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ECOLE:

ECO industrial park network for the Alpine Regions Leveraging smart and Circular Economy

Solutions for the implementation of circular economy approach in EIPs

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ECO industrial park network for the Alpine Regions **L**everaging smart and Circular **E**conomy

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ABBREVIATIONS USED

AP	Associated Partner
AS	Alpine Space
CM	Communication Manager
ECOLE	ECO industrial park network for the Alpine Regions Leveraging smart and Circular Economy
KPI	Key performance indicator
STCM	Systems thinking community model
UNIDO	United Nations International Organization
WP	Work Package
WPL	Work Package Leader

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1. Introduction

The ECOLE project, "ECO Industrial Park Network for the Alpine Regions Leveraging Smart and Circular Economy," is a collaborative project aimed at transforming industrial parks into eco-industrial parks through the application of circular economy principles. By integrating sustainability into the operations of industrial parks across the Alpine region, the project aspires to create an environmentally, socially, and economically sustainable network of industrial ecosystems.

The circular economy is an important factor of change in the field of sustainability, as it aims to change the traditional model of production and consumption. The goals of the circular economy are the systemic change to build long-term resilience, create business and economic opportunities, and provide social and environmental benefits through technical and biological cycles. It supports an economy where waste and pollution must be reduced through the conscious design of products, services and processes, and where the value of resources must be maintained for as long as possible. In this context, attention to the natural system is maximum and where the integrity of natural resources must take place through regeneration processes. The basic idea is linked to the need to preserve the value of natural resources over time through multiple uses within closed cycles. This reduces the pressure on the use of virgin natural resources by reducing the environmental impact (but not eliminating it). Ultimately, CE is inspired by natural patterns and natural flows of matter and energy that are based on regenerative cycles.

The growing attention to sustainability issues affects all sectors of the economic and social context. The 2030 Agenda proposed by the United Nations represents, in this context, the culmination of the commitments that have made it possible to define specific objectives of sustainable development at international level.

The 2030 Agenda pays close attention to the circular economy through the definition of multiple objectives related to:

1. Sustainable Consumption and Production (SDG 12),
2. Access to Clean Energy (SDG 7),
3. Good Jobs and Economic Growth (SDG 8),
4. Sustainable Cities and Communities (SDG 11),
5. Climate Action (SDG 13),
6. Life below water (SDG 14)

7. Life on Land (SDG 15).

The transition to the Circular Economy (CE) is now a goal promoted by European policies and implemented in many countries. Companies certainly play an important role in implementing circular actions and contributing to sustainable development.

This report summarizes the solutions for the implementation of Circular Economy approach in EIPs.

1.1. Definition of Circular Economy in EIPs

Industrial Parks is not a new concept. In fact, the definition of the Industrial Park based on the philosophy of integration of relative different functions (production functions, and that of services, relaxation and education) in an industrial area with majority of industrial production and services with high economic turnover and high employment. This makes it an important part in the economy.

The EIP is not a new concept, but its implementation has increased significantly over the last decades. The basic idea was established already in the 1960s following the Earth Summit "as a local collaborative set of strategies that industrial facilities can follow to more efficiently utilize materials, and to both reduce and recycle waste". Already then, EIPs were closely aligned with the circular economy concept. Interest in the notion of EIPs (from a theorical and practical point of view) increased especially since the 2000s when empirical evidence showed the growing and disproportionate share of greenhouse gas (GHG) emissions emerging from the industrial sector.

1.2. Importance of Circular Economy for Industrial Sustainability

A circular economy is an economic model designed to minimize waste and make the most of available resources. Unlike the traditional linear economy—where raw materials are extracted, processed into products, used, and then discarded—the circular economy aims to close the loop through reuse, recycling, and regeneration of materials and products.

The Industrial Park consisting variety of companies from variety of segments. That's where the variety of raw materials, natural resources required comes into picture. In addition to the raw materials requirement, a large quantity of electricity required. The utilization of such a large number of resources and the energy in the traditional linear economy makes a lot of waste which can be unsustainable approach. Introducing the circular economy approach will make the raw materials to be reused by the implementation of strategy of reduce, reuse, repair, refurbish and recycle. This will impact the Industrial system of waste management by decreasing the resource consumption, re-utilization of the resources and reducing the impact on environment.

1.3. Objectives of the Document

The objective of the document is to consolidate and show all the solutions, key development, and innovation done during the project timeline. It serves as record that capture the essence of the project's progress, including methodologies applied, challenges encountered and innovative approaches adopted to address them.

By consolidating the various components of the project into cohesive and single document, this report aims:

- To provide a clear overview of the project's scope, intent and outcomes
- To ensure transparency and traceability of work carried out.
- To facilitate knowledge sharing among stakeholders, collaborators and future practitioners.
- To highlight the practical applications and potential scalability of the solutions.
- To serve as a reference for future projects with similar goals or challenges.

The document is structured to reflect the progress of the project, with sections dedicated to specific phases, solutions domains, and innovative milestones. Together, these sections illustrate the integrated and multidisciplinary efforts undertaken by the project team.

2. Policy and Regulatory Framework

2.1. Global and Regional Policies Supporting Circular Economy

The circular economy (CE) has gained significant traction on both global and regional policy agendas as a strategy to address environmental degradation, resource scarcity, and climate change. At the global level, institutions such as the United Nations and the European Union have introduced frameworks that promote sustainable production and consumption, including the UN Sustainable Development Goals and the EU Circular Economy Action Plan. These frameworks emphasize the need to decouple economic growth from resource use through policies that support circular business models, sustainable product design, and waste reduction.

At the regional level, implementation of the circular economy requires more than just regulatory compliance—it demands a rethinking of governance structures to support the circular flow of materials and services. This transition involves aligning economic activities with environmental objectives through regionally tailored policies that encourage closed-loop systems. Local and regional governments are uniquely positioned to develop infrastructure, foster collaboration among stakeholders, and create incentives that promote circular practices within their jurisdictions.

The shift from linear to circular systems also necessitates enhanced coordination among municipalities, industries, and communities. This is particularly important in managing the spatial dimension of circularity, where proximity between production, consumption, and recycling processes is vital. Without such coordination, the potential environmental benefits of circular strategies may be offset by inefficiencies and externalities, such as increased emissions from transportation.

As a result, regional policy institutions play a pivotal role in facilitating this transition by integrating circular principles into urban planning, industrial development, and environmental regulation. Their efforts help create the enabling conditions for innovation, investment, and behavioural change that are essential to making circularity both viable and scalable.

2.2. Compliance and Legal Requirements

This section outlines the key EU compliance and legal requirements that directly support and guide the development and operation of eco-industrial parks like ECOLE. These frameworks serve as a valuable reference for similar initiatives across Europe.

1. Eco-design for Sustainable Products Regulation (ESPR)

The ESPR (Regulation (EU) 2024/1781) sets out harmonized eco-design requirements that enhance product sustainability across the EU. These requirements include durability, reparability, recyclability, and the inclusion of recycled content. The ESPR supports industrial parks in reducing environmental impacts while aligning with circular economy principles. It is complemented by the Energy Labelling Framework Regulation. The regulation will support the production and consumption patterns that are aligned with overall sustainability targets including climate, environmental, energy, resource-use and biodiversity targets while staying in the planetary boundaries which contribute to enabling products fit with a climate-neutral, resource-efficient and circular economy, reducing waste and ensuring the performance of frontrunners in sustainability.

2. Circular Economy Action Plan (CEAP)

The CEAP, updated in 2023, introduces systemic measures to reduce the EU's material footprint and dependency on primary raw materials. The CEAP provides a future oriented agenda for achieving a cleaner and more competitive Europe in co-relation with economic actors, consumers, citizens and civil society. For citizens, the circular economy will provide a high quality, functional and safe products which are efficient and affordable, last longer and are designed for reuse, repair and high-quality recycling. It also calls for:

- Binding targets on material use reduction, improving product durability, reusability, upgradability and repairability while reducing the energy consumption and increasing the energy efficiency.
- Enhanced circularity in industrial systems by enabling the remanufacturing, high quality recycling
- Incentivizing product as a service or other models where producer remains with the ownership of the product.
- National-level strategies with aspirational binding targets

These measures are essential for developing sustainable, competitive, and resilient eco-industrial zones.

3. The Clean Industrial Deal

Outlined in COM (2025) 85 final, the Clean Industrial Deal integrates climate action with industrial competitiveness. It is focused on two closely linked sectors namely: energy-intensive industries and the clean-tech sector. To make a new thriving European industrial ecosystem of growth, it is essentials to move beyond the traditional silo solutions and its entire value chain. There are in total 6 business drivers: 1) Affordable energy, 2) Lead markets, 3) Financing, 4) Circularity and access to materials, 5) Global markets and international partnerships and 6) Skills. Key pillars include:

- Decarbonization of energy-intensive industries
- Promotion of circular business models
- Establishment of lead markets for circular and sustainable products

Launch of the Industrial Decarbonization Accelerator Act This initiative sets the EU on track to become a global leader in the circular economy by 2030. This all is possible through an active engagement of industrial leaders, social partners and the civil society through Antwerp Declaration for a European Industrial Deal and the Clean Transition Dialogues.

4. Industry 5.0 Framework (EESC Opinion C/2025/108)

Industry 5.0 builds on digitalization and automation to create a more human-centric, sustainable, and resilient industrial paradigm. The EESC framework is a tool to make manufacturing more attractive and should be based on the existing European policies such as Green Deal, The Industrial Strategy, the AI Act, the Digital Decade, The European pillar of social rights and the skills agenda. Industry 5.0 principles in the design of the transformation pathways for the Industrial eco-system and the existing programme. Relevant principles include:

- Integration of circular production processes
- Emphasis on societal and environmental responsibilities
- Support for regional and SME innovation

EESC draws the attention of the decision makers to the need to develop a thorough approach to the digital innovation of the production system and the society in the era of abrupt changes aimed to enhance the regulatory profiles that ethically oriented by democratic values, social equity, fair competition and inclusive competitiveness.

5. Water Reuse Regulation

This regulation provides standards for safe and efficient water reuse in industrial contexts. It contributes to closing nutrient loops and supports eco-design aimed at reducing water consumption and preventing pollution.

6. Recovery and Resilience Facility (RRF) and European Semester

The RRF offers financial and technical support for green and digital transformations. The European Semester integrates national strategies into EU-wide economic planning, ensuring alignment with sustainability and circular economy goals.

2.3. Incentives and Funding Opportunities

1. **Innovation Fund – EU's Flagship for Climate Innovation and Clean Technologies**

The Innovation Fund is a major EU financing mechanism designed to support the market deployment of cutting-edge low-carbon technologies. It plays a critical role in meeting the EU's climate neutrality objectives, enhancing industrial competitiveness, and fostering sustainable job creation across Europe.

Purpose and Strategic Role

The Innovation Fund aims to accelerate the deployment of breakthrough clean technologies across energy-intensive sectors. By supporting first-of-a-kind, high-impact projects, it helps reduce greenhouse gas emissions while positioning the EU as a global leader in industrial decarbonisation.

This strategic mission aligns with the EU's climate and energy policy agenda, and directly contributes to initiatives such as:

- REPowerEU Plan – focused on boosting energy independence and accelerating renewable energy use.
- Hydrogen Bank – facilitating clean hydrogen production and infrastructure.
- Green Deal Industrial Plan – supporting green manufacturing and industrial competitiveness.
- Net-Zero Industry Act – promoting development and scale-up of net-zero technologies.

Funding Source and Size

The Innovation Fund is financed through revenues generated by the auctioning of approximately 530 million allowances under the EU Emissions Trading System (EU ETS), the world's largest carbon pricing scheme. The total funding available from 2020 to 2030 is expected to reach up to €40 billion, depending on the carbon price (assumed at €75 per tonne of CO_2). Additionally, the Fund includes unspent resources from the previous NER300 programme.

Scope of Funding

The Fund targets projects that offer high potential for emissions reduction and demonstrate technological innovation. Areas of support include:

- Low-carbon technologies in energy-intensive industries (e.g., cement, steel, chemicals)
- Carbon Capture and Utilisation (CCU) and Carbon Capture and Storage (CCS)
- Innovative renewable energy generation (solar, wind, biomass)
- Energy storage solutions
- Net-zero mobility in aviation, maritime, and road transport
- Decarbonisation of buildings and circular construction

Eligible Countries and Applicants

The Innovation Fund is open to applicants from all EU Member States, as well as Norway, Iceland, and Liechtenstein. Eligible entities include private companies, public institutions, research organisations, and consortia. Projects must demonstrate:

- High innovation and emissions reduction potential
- Sufficient technical, financial, and legal maturity
- Replicability across EU markets or sectors
- Cross-border cooperation and strong climate impact are viewed positively in the evaluation process.

Types of Financial Support

The Innovation Fund offers a flexible and risk-sharing approach through several financial mechanisms:

- Regular Grants – Cover up to 60% of eligible costs (CAPEX and OPEX, minus revenues over 10 years). Up to 40% may be disbursed early based on milestones.
- Competitive Bidding (Auctions) – Introduced in 2023, allows for 100% coverage of eligible costs, with funding released during operational phases based on performance.
- Project Development Assistance (PDA) – Delivered by the European Investment Bank, provides technical and financial support to improve project bankability.
- Blending with Other EU Programmes – Projects may combine Innovation Fund support with:
    - Horizon Europe
    - InvestEU
    - Just Transition Fund
    - Connecting Europe Facility (CEF)
    - Modernisation Fund

Although the Innovation Fund grant itself is not considered state aid, any additional public funding must comply with EU state aid rules.

2. **LIFE – Circular Economy and Quality of Life: 2025 Funding Opportunities**

The LIFE sub-programme **"Circular Economy and Quality of Life"** provides targeted financial support to implement innovative, scalable solutions that advance the EU's transition to a sustainable, circular, toxic-free, and climate-resilient economy. The 2025 call cycle includes four major funding opportunities supporting technical pilots, environmental governance, regional planning, and capacity-building.

Each call offers a 60% co-financing rate and is open to legal entities across the EU, EEA, and eligible neighbouring countries.

Overview of 2025 LIFE Calls

Call Title	Deadline	Call Budget	EU Contribution per Project
Circular Economy and Zero Pollution	23 Sep 2025	€77,000,000	€2,000,000 – €10,000,000
Environment Governance	23 Sep 2025	€4,000,000	€700,000 – €2,000,000
Strategic Integrated Projects – Environment (SIPs)	04 Sep 2025	€56,000,000	€10,000,000 – €30,000,000
Technical Assistance for SIP Preparation	23 Sep 2025	€300,000	Fixed at €70,000

Applicants planning to respond to any of the LIFE 2025 calls under the "Circular Economy and Quality of Life" sub-programme should carefully consider the following:

Eligibility Requirements

Applicants must be legal entities (public or private) established in:

- EU Member States, including Overseas Countries and Territories (OCTs);
- LIFE-associated non-EU countries (e.g. Iceland, Moldova, Ukraine, North Macedonia).

Natural persons (except sole traders under certain legal conditions) and EU institutions (except the Joint Research Centre) are not eligible. International organisations can only participate under limited conditions.

Project Focus and Alignment

Proposals should clearly align with EU environmental policy goals, particularly:

- The European Green Deal
- The Circular Economy Action Plan
- The Zero Pollution Action Plan
- National or regional circular economy strategies

Proposals that demonstrate policy integration, contribute to legislative implementation, and offer potential for systemic change are evaluated more favourably.

3. **InvestEU Programme – Driving Sustainable Investment in Europe**

The InvestEU Programme is the EU's flagship investment mechanism to support sustainable growth, innovation, and employment across Europe. Launched as a successor to the Investment Plan for Europe (the Juncker Plan) and building on the success of the European Fund for Strategic Investments (EFSI), InvestEU brings together 14 formerly independent EU financial instruments into a single streamlined framework.

Programme Structure

InvestEU is built on three key pillars:

- **InvestEU Fund:** Provides an EU budget guarantee of €26.2 billion to de-risk investments and attract private capital. It is expected to mobilise over €372 billion in public and private investment across the EU.
- **InvestEU Advisory Hub:** Offers technical assistance, project structuring, and capacity-building support for project promoters.
- **InvestEU Portal:** A matchmaking platform that connects project promoters with investors across the EU.

Investment Priorities and Circular Economy Relevance

InvestEU finances economically viable projects aligned with EU policy priorities, including the European Green Deal and the Just Transition Mechanism. A minimum of 30% of all investments is reserved for climate and environmental action, rising to 60% in the Sustainable Infrastructure window.

InvestEU targets four key policy areas:

1. Sustainable Infrastructure
2. Research, Innovation, and Digitalisation
3. Small and Medium-sized Enterprises (SMEs)
4. Social Investment and Skills

Eligibility

Eligible final recipients include a wide range of public and private actors:

- Small and medium-sized enterprises (SMEs)
- Small mid-cap companies
- Social or micro-enterprises
- Public sector entities (e.g. municipalities, regional authorities)
- Private entities (e.g. project companies, SPVs, corporates)
- Mixed entities such as public-private partnerships (PPPs)

Applicants must be established in an EU Member State or in a third eligible country under the InvestEU framework.

Financing Instruments

InvestEU supports both direct and intermediated financing, tailored to project size and maturity. Instruments include:

- Loans and guarantees (via the EIB Group or national promotional banks)
- Equity or quasi-equity financing
- Blended finance solutions
- Technical assistance for project preparation through the Advisory Hub

Projects must be economically viable and comply with EU environmental, social, and procurement standards.

Strategic Fit for Circular Economy and EIPs

InvestEU is highly relevant for industrial parks and circular economy initiatives that require long-term investment, especially in:

- Industrial symbiosis infrastructure (e.g. heat, waste, water loops)
- Shared facilities for recycling, remanufacturing, or waste treatment
- Green retrofitting of industrial buildings and utilities
- Scaling up circular SMEs or clusters within Eco-Industrial Parks (EIPs)
- Blending with LIFE, Horizon Europe, or national co-financing

In addition to the major EU-level funding instruments, project promoters should be aware that further opportunities are available through national and regional programmes across the EU. These are often tailored to specific local priorities, offering co-financing for infrastructure, innovation, and industrial transition. When planning circular economy initiatives, especially those embedded in industrial parks or regional ecosystems,it is advisable to explore these complementary funding sources to enhance financial viability, build partnerships, and align with territorial development goals. Integrating support from multiple levels can significantly increase the scale, impact, and long-term sustainability of circular investments.

3. Key Principles of Circular Economy in EIPs

3.1. Industrial Symbiosis and Resource Sharing

Industrial Symbiosis (IS) and Resource Sharing represent critical enablers for the effective operationalization of Circular Economy (CE) principles within Eco-Industrial Parks (EIPs). These mechanisms are instrumental in facilitating closed-loop systems of material, energy, water, and by-product flows, thereby fostering systemic efficiency, reducing environmental impact, and enhancing economic resilience across industrial ecosystems.

Industrial Symbiosis shall be understood as the process by which traditionally separate industries engage in a collaborative approach to achieve competitive advantage through the physical exchange of materials, energy, water, and/or by-products. This exchange is facilitated by geographic proximity, sectoral compatibility, or systemic coordination and must be predicated on principles of mutual benefit, operational feasibility, and regulatory compliance.

Resource Sharing, as a complementary construct, includes the shared utilization of infrastructure, utilities, equipment, services, and logistical frameworks among industrial actors within the EIP. The strategic co-use of such resources aims to reduce redundancy, optimize load capacity, and minimise lifecycle costs while ensuring that resource efficiency objectives are holistically addressed.

Industrial Symbiosis and Resource Sharing may take diverse forms but not limited to Material Exchange, Energy Cascading, Water reclamation and Reuse, Shared Logistics and Infrastructure, shared Utilities and Services. To enable and foster the successful implementation of Industrial Symbiosis and Resource sharing; Data Transparency and Exchange, Stakeholder Engagement, Legal Certainty, Technological compatibility, Economic Incentives and Monitoring and Verification is important.

Together, these constructs provide a structural basis for achieving higher-order circularity in industrial clusters and are to be considered foundational components in the design and retrofitting of EIPs under national and international circular economy frameworks.

3.2. Waste Minimization and Recycling Strategies

Waste minimization and recycling strategies constitute a central pillar of Circular Economy (CE) implementation in Eco-Industrial Parks (EIPs), facilitating the decoupling of industrial growth from environmental degradation. These strategies seek to reduce the generation of waste at source, optimize the recovery of materials and energy from unavoidable residuals, and reintroduce recycled resources into industrial value chains, thereby fostering closed-loop production systems and enhancing resource circularity.

Waste Minimization refers to systematic actions taken by industrial actors to prevent or reduce the quantity and hazardous nature of waste generated during production, processing, packaging, distribution, and maintenance activities. This includes both process-level interventions and systemic design changes aimed at enhancing material efficiency and reducing environmental burden.

Recycling Strategies, within the context of EIPs, are defined as the coordinated and regulated recovery of materials from industrial waste streams, their transformation into secondary raw materials, and their reintegration into production processes, either on-site, within the park, or through external partnerships. Recycling activities must comply with all applicable environmental, health, and safety standards, and must not result in the downcycling of materials where higher-value recovery is technically and economically viable.

In accordance with the waste hierarchy, waste minimization and recycling strategies in EIPs must prioritize the sequential actions like Prevention, Reduction, Reuse, Recycling, Recovery, and Disposal. Strategies adopted by EIPs must be demonstrably oriented toward the upper tiers of the hierarchy and supported by technical and economic assessments to ensure optimal outcomes.

The operationalization of waste minimization and recycling in EIPs requires a multi-faceted approach that incorporates the technical and systemic interventions such as Process Optimization, Product redesign and substitution, Closed-Loop Water and Material Systems, Waste Audits and Material Flow Analysis, Decentralized and Centralized Recycling Facilities, and Reverse Logistics and Take back Mechanism. All recycling operations must meet performance benchmarks for material recovery rates, energy consumption, emissions, and occupational safety, as defined by regulatory agencies and industry standards.

The combined implementation of waste minimization and recycling contributes to the overall sustainability, competitiveness, and regulatory compliance of EIPs, and shall be integrated at the planning, operational, and monitoring phases of park development and management.

3.3. Renewable Energy Integration

The integration of renewable energy (RE) systems into Eco-Industrial Parks (EIPs) represents a fundamental principle for advancing the transition toward circular and low-carbon industrial ecosystems. Renewable Energy Integration (REI) within EIPs is essential not only for reducing dependency on finite fossil resources but also for enhancing energy resilience, lowering greenhouse gas (GHG) emissions, and fostering regional energy self-sufficiency. The strategic deployment of renewable energy sources in EIPs supports the decarbonisation agenda and is intrinsically aligned with broader climate, energy, and circular economy objectives at the national and supranational levels.

Renewable Energy Integration refers to the systematic incorporation of energy generated from naturally replenishing sources—such as solar, wind, biomass, hydro, and geothermal—into the energy systems of EIPs. This integration includes both on-site generation and off-site procurement through renewable power purchase agreements (PPAs), community energy schemes, and green grid supply mechanisms.

The scope of REI encompasses the generation, storage, distribution, and use of renewable energy within the industrial park boundaries and in its immediate vicinity. It also includes the harmonisation of industrial energy demand with the availability of variable renewable resources through demand-side management, smart grid technologies, and sector coupling strategies.

Renewable energy deployment in EIPs shall be in accordance with prevailing energy laws, national renewable energy action plans, and regional decarbonisation frameworks and should comply

- Adherence to grid interconnection protocols and electricity market regulations;
- Conformity with licensing and permitting requirements for renewable energy installations;
- Compliance with feed-in tariff, net metering, or renewable energy certificate (REC) mechanisms where applicable;

- Alignment with national commitments under international agreements such as the Paris Agreement and the EU Renewable Energy Directive (Directive (EU) 2018/2001)

A diverse portfolio of renewable energy technologies is applicable to the EIP context, each with unique spatial, technical, and economic considerations. These include Solar Photovoltaic, Solar Thermal, Biomass and Biogas, Wind Energy, Geothermal Energy, Hydropower. The selection and deployment of renewable energy systems shall be guided by techno-economic feasibility studies, environmental impact assessments, land-use compatibility analyses, and long-term energy planning strategies.

Renewable Energy Integration in EIPs requires the development of robust energy infrastructure capable of accommodating intermittent generation, balancing demand, and enabling flexible energy use. Essential components are such as Smart Grid and Energy Management Systems, Energy Storage Systems, District Heating and Cooling Networks, Power purchase and Wheeling Mechanism. The infrastructure development must conform to engineering standards, safety codes, and energy efficiency directives applicable to industrial energy systems.

An effective Monitoring, Reporting and Verification framework is essential to evaluate the performance and compliance of Renewable Energy Initiatives within EIPs. The Key indicators can be Installed renewable energy capacity by technology, Renewable energy generation and consumption, shares of renewables in EIPs energy mix, GHG emissions avoided through RE use, Energy cost savings, and finally the system reliability and energy resilience metrics.

Renewable energy strategies should be embedded into the EIP master planning process, enterprise sustainability reporting frameworks, and regional energy transition roadmaps.

3.4. Sustainable Procurement and Green Supply Chain

Sustainable procurement and the establishment of a green supply chain are integral to the successful implementation of Circular Economy (CE) principles within Eco-Industrial Parks (EIPs). These strategies emphasize the adoption of environmentally responsible sourcing practices, the promotion of resource efficiency, and the minimization of ecological footprints throughout the entire supply chain lifecycle. By prioritizing sustainability in procurement processes and supply chain management, EIPs can facilitate the transition to a circular, low-carbon industrial ecosystem, drive innovation, and enhance long-term economic and environmental performance.

Sustainable Procurement refers to the acquisition of goods, services, and works that minimize negative environmental, social, and economic impacts over their entire lifecycle. It entails sourcing products and services with reduced environmental footprints, fostering ethical business practices, and promoting social responsibility, while also ensuring cost-effectiveness and quality.

A Green Supply Chain is one that integrates environmental considerations into supply chain management, focusing on resource efficiency, waste reduction, and the minimization of pollution. It involves the identification, selection, and management of suppliers and service providers who prioritize sustainability, use of renewable resources, waste minimization, and environmentally responsible production methods. Within the context of EIPs, the green supply chain extends to include both upstream (raw materials sourcing) and downstream (distribution, usage, and disposal) activities.

Green supply chain management involves the integration of environmental criteria into all stages of the supply chain, from raw material extraction to end-of-life disposal or recycling. It includes a range of activities aimed at reducing resource use, minimizing waste generation, and promoting the use of environmentally friendly processes and materials. The key elements of a green supply chain within an EIP include Sustainable Sourcing of Raw Materials, Energy Efficiency in Manufacturing and Logistics, Design for Disassembly and Recycling, Waste Reduction and Reverse Logistics and Environmental Risk Management.

Both sustainable procurement and green supply chains are key enablers of the circular economy model, promoting the use of renewable resources, the reduction of environmental harm, and the effective management of waste and emissions.

4. Strategies for Implementation

4.1. Material Flow Optimization

Material flow optimization is a foundational strategy in implementing circular economy principles within production systems. It aims to enhance the efficiency of material usage, reduce waste, and minimize unnecessary energy and time expenditures associated with production processes. The key objective is to transform the flow of materials into a more streamlined, cost-effective, and resource-efficient system.

A structured approach begins with an analysis of the existing material flow, examining interdepartmental movements, intra-departmental logistics, and individual machine operations. This diagnostic phase identifies inefficiencies and bottlenecks, laying the groundwork for planning an ideal material flow. Through macroanalysis (between departments) and microanalysis (within departments), production cells and part families are defined to localize and simplify processes. This results in fewer transitions between departments and improved layout arrangements that better match the actual needs of production.

The transformation from traditional workshop production to cell-based production systems is central to material flow optimization. Cell production groups similar machines and parts to reduce flow times, setup times, and non-value-added activities like idle waiting or excessive transport. This approach not only improves resource utilization but also boosts employee engagement by enhancing task variety and ownership.

By implementing this optimization strategy, companies can achieve tangible results: reductions in internal transport costs, shorter order lead times, more predictable delivery schedules, and increased operational efficiency. Ultimately, material flow optimization supports the broader goals of a circular economy by fostering sustainable, lean, and adaptive manufacturing environments.

4.2. Closed-Loop Production Systems

A closed-loop production system centers on designing and organizing manufacturing operations to enable continuous circulation of materials and components across the product life cycle. This strategy integrates design, production, use, and post-use phases to retain product value and eliminate linear material flows.

The approach starts with design for disassembly, upgradability, and multi-life functionality. Products are intentionally engineered for ease of maintenance, part replacement, refurbishment, and end-of-life recovery. This reduces dependency on virgin materials and simplifies downstream processes like remanufacturing and recycling.

At the system level, closed-loop production requires alignment between design teams, manufacturing operations, and recovery partners. Production cells and supply chains are configured to support reverse logistics, modular subassembly exchange, and standardized part reuse. Manufacturing processes are selected not only for initial efficiency but also for their compatibility with circular material flows, such as clean separation of components and minimal contamination during use.

Dedicated evaluation frameworks—such as life cycle metrics and circularity compliance indicators—are employed to guide decisions across the loop. These include measurable aspects like material circularity index, product recovery rate, and resource longevity. Digital tools, including product passports and IoT-enabled traceability, are increasingly integrated to monitor and optimize resource loops in real time.

The system also incorporates planning for end-of-life strategies from the outset. This includes identifying viable re-entry pathways such as component remanufacturing, functional upgrades, and value-retaining recycling. Coordination with third-party recovery agents and infrastructure partners is essential to execute these pathways effectively.

By establishing a closed-loop architecture, production systems reduce process losses, extend product lifespans, and preserve material value across multiple cycles—forming a foundational mechanism for operationalizing circularity.

4.3. Water Conservation and Recycling Solutions

Effective water conservation and recycling strategies involve minimizing withdrawal, maximizing reuse, and recovering both water and embedded resources through tailored approaches across sectors. These strategies can be grouped into three operational categories: decreasing use, optimizing use, and retaining water within the system.

To decrease water use, Avoid, Reduce, and Replace are applied. Avoid eliminates water use entirely in certain processes by substituting technologies or redesigning systems (e.g., dry cleaning or waterless toilets). Reduce minimizes water consumption through efficiency measures such as precision irrigation, low-flow fixtures, or process innovations in manufacturing. Replace substitutes high-quality freshwater with alternative sources like greywater or non-potable water, or in some cases, replaces water entirely with other media (e.g., heat transfer fluids).

To optimize water use, Reuse, Recycle, and Cascade strategies are adopted. Reuse involves applying water again without treatment, often in nearby or same-loop processes—such as using cooling water multiple times. Recycle uses treatment technologies to restore water quality for further applications; this can include physical, chemical, or biological processes depending on end-use requirements. Cascading organizes sequential uses of the same water, such as routing water from industrial processes to cleaning, then flushing, and finally irrigation, integrating multiple strategies into one extended flow.

To retain water within managed systems, Store and Recover strategies are implemented. Store keeps water available for future use in tanks, basins, or underground systems, allowing flexibility across time. Recover focuses on extracting materials or energy from water streams—such as phosphorus, heat, or methane from wastewater—often alongside water recovery.

These strategies require cross-disciplinary planning and system design that aligns water quality requirements, timing, and spatial constraints, and are often supported by smart monitoring technologies, modular infrastructure, and decentralized solutions.

4.4. Energy Efficiency and Renewable Energy Adoption

This strategy focuses on redesigning energy systems to improve operational efficiency and incorporate renewable sources across all levels of industrial and regional infrastructures. It involves a portfolio of technological and system-level approaches to decarbonize energy supply and reduce energy input per unit of output.

Key actions include the electrification of heat and power systems, especially in process industries, where electrified heating combined with energy recovery networks can replace conventional fossil-fuel-based systems. Integration of solar, geothermal, and biomass technologies is enabled through optimization models that align generation with temporal and spatial demand patterns.

Operational improvements are achieved through energy system optimization methods, including model predictive control (MPC), non-linear MPC, and hierarchical scheduling. These are applied to balance supply-demand fluctuations, minimize curtailment of renewables, and maximize flexibility through system inertia and heat storage capabilities. In agricultural contexts, robust control models have been used in greenhouses to align renewable inputs with environmental control systems, improving both energy performance and crop productivity.

Infrastructure enhancement is also critical. Emerging solutions like 6G wireless networks support smart grid coordination, real-time energy trading, and weather-integrated forecasting for renewables. These systems enable more responsive and adaptive energy management.

At the technology level, adoption of high-efficiency devices—such as hybrid photovoltaic-thermal (PV/T) units—and the use of advanced materials like phase change materials (PCMs) embedded with metal foams enhance both energy conversion and storage. Such materials improve the performance of thermal energy systems across industrial and building sectors.

This strategy is underpinned by computational tools, including machine learning, quantum computing, and metaheuristic optimization algorithms, which support system-wide energy planning, real-time decision-making, and material innovation.

4.5. Digitalization and Smart Technologies in Circular Economy

Digital technologies (DTs) form a strategic foundation for implementing circular practices across product lifecycles. This strategy involves leveraging tools such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing, big data analytics, and digital twins to enable data-driven, adaptive, and automated operations that support circular goals.

At the product design stage, digital tools facilitate the integration of circularity principles by supporting modularity, reparability, and disassembly. Technologies like additive manufacturing allow for low-waste production and customization, while digital twins provide real-time feedback loops that connect design parameters with downstream performance, enabling iterative improvement.

During the use phase, smart product-service systems (PSSs) enabled by IoT and cloud platforms allow companies to monitor usage patterns, predict maintenance needs, and optimize resource efficiency. These systems shift value creation from the point of sale to the duration of use, encouraging longer product lifespans and access-based consumption models.

At end-of-life, digital platforms and smart infrastructure enable efficient reverse logistics. Smart bins, sensor networks, and AI-based sorting systems automate and optimize the collection and classification of materials. Blockchain and traceability systems enhance transparency and accountability in product recovery and remanufacturing.

These technologies are interconnected through a digital ecosystem that supports lifecycle thinking and cross-sector collaboration. With real-time data acquisition and advanced analytics, businesses can adapt to dynamic conditions, personalize offerings, and make evidence-based decisions that enhance material circularity.

5. Business Models Supporting Circular Economy

5.1. Shared Infrastructure and Resource Efficiency

In the context of advancing circular economy (CE) principles within Eco-Industrial Parks (EIPs), the deployment of shared infrastructure and the promotion of resource efficiency represent core strategic mechanisms that facilitate industrial symbiosis, reduce operational costs, and contribute to the decoupling of economic growth from environmental degradation. The design, development, and governance of shared infrastructure systems must be underpinned by robust policy instruments, cooperative business models, and cross-sectoral stakeholder engagement to ensure their long-term viability and alignment with both national and international sustainability objectives.

Shared infrastructure in EIPs refers to the collective utilization of facilities, utilities, and services by multiple tenant enterprises operating within a geographically proximate industrial zone. Such infrastructure may encompass, inter alia, centralized wastewater treatment plants, cogeneration (combined heat and power) units, material recovery and recycling facilities, shared logistics platforms, and common effluent treatment systems. This model is predicated upon the foundational CE tenet of closing material and energy loops, thereby minimizing waste generation and optimizing resource inputs.

The rationale for shared infrastructure is multifaceted: it mitigates redundant capital expenditure, improves the load factor of essential utilities, fosters a culture of cooperation among park tenants, and enables access to otherwise cost-prohibitive clean technologies. In parallel, resource efficiency—defined as the ratio of economic output to natural resource input—becomes operationally feasible and financially attractive within such collaborative settings. Resource efficiency strategies within EIPs may include but are not limited to waste valorisation, cascading use of energy, water reuse, and process integration across firms.

The success of shared infrastructure systems hinges upon appropriate governance structures and institutional arrangements that balance the interests of multiple stakeholders while ensuring operational reliability and equitable cost-sharing. Three principal models of governance are typically observed:

- **Park Authority-led Model**: A central administrative body—often a public-private partnership entity—plans, develops, and operates shared infrastructure, charging tenant firms on a usage basis.
- **Consortium-based Model**: Tenant firms form a consortium or cooperative society with joint ownership of infrastructure assets, governed by a formal agreement that outlines rights, responsibilities, cost allocation, and conflict resolution mechanisms.
- **Third-party Operator Model**: An independent service provider is contracted to design, build, and manage infrastructure under a long-term concession or service agreement, subject to performance indicators and environmental standards.

Irrespective of the model adopted, transparency in financial transactions, enforceability of service-level agreements, and access to grievance redressal mechanisms are critical for institutional credibility and sustained participation.

Internationally, there are several examples who has demonstrated an efficacy of shared infrastructure in advancing circularity goals. For instance: Our partner Grenoble Alpes Metropole has been a successful example. They have established a collaborative effort with Hytech Vallee who are driving resource efficiency and environmental responsibility with industrial eco-system.

5.2. Product-as-a-Service (PaaS) Model

The transition toward a circular economy necessitates a fundamental shift in the way products are designed, delivered, and consumed. One of the most transformative models enabling this shift is the Product-as-a-Service (PaaS) business model. Within the context of Eco-Industrial Parks, the PaaS model presents significant opportunities to decouple resource consumption from economic output by promoting longevity, reuse, and resource optimization throughout the product lifecycle.

The PaaS model replaces traditional linear sales transactions with service-oriented arrangements, wherein customers obtain access to products under usage-based contracts rather than acquiring ownership. This paradigm shift allows manufacturers and service providers to retain ownership and stewardship over their products, thereby incentivizing durability, reparability, and end-of-life recovery.

The Product-as-a-Service model encompasses various delivery formats, including leasing, performance-based contracting, pay-per-use, subscription models, and outcome-based service agreements. These formats are applicable across multiple sectors—ranging from industrial machinery and transportation to lighting, HVAC systems, and office equipment.

In the PaaS model, the economic value of a product is not realized through its one-time sale, but through its extended use and the provision of associated services over time. This inherently aligns with the core principles of the circular economy, namely:

- **Extending product lifecycles** through maintenance, refurbishment, and upgrades
- **Increasing utilization rates** by serving multiple users over a product's life
- **Facilitating take-back and reverse logistics** for material recovery
- **Incentivizing design for durability and modularity**.

Within EIPs, the PaaS model enhances resource efficiency, reduces material waste, and creates inter-firm service networks that promote collaboration and innovation.

The application of the PaaS model within EIPs can generate tangible circular outcomes across multiple industrial segments. Illustrative applications include:

- **Industrial Equipment Leasing**: Firms within the EIP can access heavy-duty machinery or specialized production equipment on a subscription or pay-per-use basis, thereby reducing upfront capital expenditure and encouraging shared utilization.
- **Energy-as-a-Service**: On-site renewable energy installations (e.g., solar PV, biomass boilers) operated by third-party providers can deliver power or heat under performance contracts, linking payments to output or efficiency metrics.
- **Office and IT Equipment-as-a-Service**: Shared office spaces and service centres within EIPs can operate under a model in which printers, computers, and other devices are leased and maintained by the manufacturer, with periodic upgrades and end-of-life take-back.
- **Water-as-a-Service and Chemical Leasing**: Particularly relevant for water-intensive or chemical-dependent operations, service providers retain ownership of treatment systems or chemicals and are compensated based on performance or treated output rather than volume consumed.

By embedding the PaaS model into operational frameworks, EIPs can minimize material throughput, reduce idle asset time, and improve the overall sustainability profile of participating firms.

The implementation of PaaS in industrial settings necessitates well-defined contractual agreements that outline roles, responsibilities, payment structures, risk-sharing mechanisms, and performance indicators. Key considerations include:

- **Ownership and liability**: Contracts must delineate the legal ownership of the product, liability in the event of malfunction, and responsibilities for repair, maintenance, and insurance.
- **Performance metrics**: Service-level agreements (SLAs) must include measurable and enforceable criteria such as uptime, energy savings, product output, or cost savings, which serve as the basis for remuneration.
- **Data ownership and access**: As many PaaS models rely on digital monitoring and IoT integration, agreements must address data privacy, access rights, and cybersecurity provisions.
- **End-of-contract provisions**: These include return logistics, options for renewal or upgrade, and terms for product refurbishment or recycling.

Where multiple tenants in an EIP utilize the same PaaS provider, a centralized coordination body (such as a park operator or facility manager) may facilitate aggregation, collective bargaining, and oversight of service quality.

The PaaS model offers several benefits to both service providers and client firms:

- **Predictable cost structures**: Usage-based billing models reduce financial uncertainty and allow firms to convert capital expenditure into operational expenditure.
- **Access to advanced technologies**: Firms can deploy state-of-the-art equipment without bearing the full cost of ownership, fostering innovation and competitiveness.
- **Increased asset utilization**: Providers have an incentive to design products that are durable and modular, reducing the cost-of-service delivery while enhancing value retention.

- **Environmental compliance and branding**: Retained ownership allows providers to ensure that products are disposed of responsibly, contributing to environmental reporting and circular economy compliance.

5.3. Reverse Logistics and Remanufacturing

In the strategic pursuit of a circular economy, reverse logistics and remanufacturing constitute indispensable pillars that enable the recovery, revalorization, and reintegration of materials and products into industrial value chains. When integrated into the operational and infrastructural frameworks of Eco-Industrial Parks (EIPs), these mechanisms not only support environmental objectives but also open up new business opportunities, reduce dependency on virgin raw materials, and enhance industrial resilience.

This section outlines the functional dynamics, regulatory requirements, governance frameworks, and implementation strategies for reverse logistics and remanufacturing within EIPs, highlighting their contribution to circular economy transition pathways.

Reverse logistics refers to the systematic process of collecting used products, components, and materials from end-users, distributors, or points of consumption and transporting them backward through the supply chain for the purposes of reuse, recycling, refurbishing, or disposal. It encompasses activities such as product return management, collection infrastructure, transport, sorting, and handling.

Remanufacturing, by contrast, is an industrial process whereby used products or components are restored to like-new condition and performance, often involving disassembly, inspection, cleaning, replacement of worn parts, reassembly, and testing. Remanufacturing typically adheres to rigorous quality assurance protocols and may meet or exceed the performance specifications of newly manufactured items.

Together, reverse logistics and remanufacturing create closed-loop systems that are fundamental to extending product lifespans, reducing material throughput, and achieving the high-value retention goals of circular economy frameworks.

Within EIPs, reverse logistics and remanufacturing can be structured through various business model configurations that promote inter-firm collaboration and resource exchange. These may include:

- **Third-party remanufacturing partnerships**, where specialized service providers operate remanufacturing units and offer contract services to multiple firms.
- **Closed-loop producer systems**, where original equipment manufacturers (OEMs) retain ownership of their products and operate in-park recovery and remanufacturing hubs.
- **Inter-tenant exchanges**, facilitated through park-level digital platforms, allowing one firm's returned goods, spare parts, or waste streams to serve as inputs for another firm's operations.
- **Shared logistics networks**, where the costs and capacities of reverse transport are jointly managed by multiple EIP tenants through centralized or cooperative arrangements.

These collaborative models' lower transaction costs, enable economies of scale, and foster innovation ecosystems that are critical to the viability of reverse logistics and remanufacturing.

5.4. Extended Producer Responsibility (EPR)

Extended Producer Responsibility (EPR) is a policy approach and regulatory instrument that assigns significant responsibility—financial and/or physical—to producers for the post-consumer phase of their products. It serves as a foundational enabler of circular economy business models by internalizing the external costs of end-of-life product management and promoting product design improvements that facilitate reuse, recycling, and resource recovery.

In the context of Eco-Industrial Parks, EPR functions as both a compliance framework and a business model driver. By creating incentives and obligations for producers to manage their products after consumption, EPR mechanisms can accelerate the development of closed-loop systems, encourage investment in reverse logistics and recycling infrastructure, and foster industrial symbiosis among co-located firms.

Extended Producer Responsibility is grounded in the principle of "polluter pays" and operationalizes the concept of life-cycle thinking in product stewardship. Under EPR, producers—defined broadly to include manufacturers, brand owners, importers, and distributors—are made responsible for:

- Collection and take-back of products after use
- Sorting, dismantling, and recycling or recovery of materials
- Environmentally sound disposal of residual waste
- Public awareness and information dissemination
- Reporting, monitoring, and financing of post-consumer waste management systems.

EPR schemes may be mandatory under law or voluntarily adopted by industry associations, often supported by government accreditation. They may be individual (individual producer responsibility, IPR) or collective (collective producer responsibility, CPR) depending on the product category and market structure.

EPR is embedded in the legal frameworks of numerous jurisdictions and is increasingly recognized as a best practice in waste governance and circular economy strategies.

European Union: EPR is mandated under the Waste Framework Directive (2008/98/EC), the Packaging and Packaging Waste Directive (94/62/EC), and sector-specific directives (e.g., WEEE, ELV, Batteries). The EU Circular Economy Action Plan (2020) calls for extending EPR to new product groups and strengthening enforcement.

OECD Guidelines: The OECD Council Recommendation on EPR (2001) provides guidance on designing and evaluating EPR schemes, emphasizing cost efficiency, transparency, and stakeholder engagement.

For EIPs operating within these jurisdictions, alignment with EPR regulations is not optional but integral to legal compliance, industrial licensing, and access to certain markets.

EIPs provide an ideal setting for collective and efficient implementation of EPR schemes due to their physical proximity, shared infrastructure, and potential for coordinated governance. EPR can be operationalized within EIPs through:

- **Producer Responsibility Organizations (PROs)** established jointly by EIP tenants to manage collection, sorting, and recycling obligations.
- **On-site treatment facilities**, such as material recovery facilities (MRFs), dismantling units, or e-waste processing centres, designed to serve multiple producers under a pooled resource model.

- **Centralized reporting and compliance administration**, managed by the EIP operator or an accredited third party, streamlining regulatory submissions, audit processes, and data aggregation.
- **Integration with digital tracking systems**, including QR codes, serial numbers, and digital product passports to track producer responsibility from product entry to end-of-life processing.

These systems reduce per-unit compliance costs, improve material recovery rates, and create a transparent environment for monitoring and regulatory enforcement. EPR is more than a regulatory obligation; it can be leveraged as a business model component to support competitive differentiation, product innovation, and resource security. Key business model implications include:

- **Design for Environment (DfE)**: Producers are incentivized to design products that are more durable, repairable, modular, and recyclable to reduce take-back and end-of-life costs.
- **Service-based models**: Producers may transition to Product-as-a-Service (PaaS) models to retain control of their products and fulfil EPR obligations more effectively.
- **Secondary material sourcing**: EPR creates internal streams of recovered materials, which can be reintegrated into production processes, reducing reliance on virgin resources.
- **Brand positioning**: Compliance with robust EPR practices enhances corporate reputation, particularly with environmentally conscious consumers and institutional buyers.

In EIPs, such business models can be supported by cooperative arrangements, where manufacturers share recycling infrastructure and collectively benefit from economies of scale in resource recovery.

Internationally, there are several examples who has demonstrated an efficacy of Extended Producers Responsibility in advancing circularity goals. For instance: Our partner Technology centre for energy has a successful example. There partner Siemens Technopark hosts a company called Flender, which has been successfully acting as per EPR. They often work with their users like windmill owners to provide a constant support and upgrade the windmill generators whenever needed; as in many cases the life cycle of generator sometimes crosses even 20 years.

6. Case Studies and Best Practices

6.1. Successful Implementation Examples from Various Industries

In alignment with the European Union's objectives on circular economy and sustainable development, numerous industrial zones across Europe have demonstrated practical and scalable models for implementing circular economy principles within Eco-Industrial Parks (EIPs). These successful implementations serve as critical references for replication and policy formulation.

Trieste Industrial Cluster, Italy – Digital Exchange Portal

The industrial cluster based in Trieste, Italy, has leveraged digitalization to foster material exchange and resource optimization through the development of a dedicated online portal. This platform facilitates real-time listing and exchange of both input raw materials and output by-products among participating enterprises within the cluster.

By enabling visibility into the availability and demand for specific materials, the portal enhances the potential for industrial symbiosis and reduces reliance on external raw material procurement. This system also contributes to reducing waste generation, as by-products from one process become valuable inputs for another.

The Trieste portal is a compelling example of how digital technologies can be harnessed to operationalize circularity within industrial ecosystems.

Siemens Technopark, Ruhstorf, Germany – Metallic Circular Economy

The Siemens Technopark located in Ruhstorf exemplifies a strategic integration of sustainability principles during the earliest phases of infrastructure design and industrial development. A significant factor contributing to its success lies in the deliberate incorporation of circularity-oriented criteria in the master planning phase. This includes provisions for modular infrastructure, energy-efficient building materials, and integrated waste management systems.

One of the key tenants of the Technopark, the firm Flender, has implemented an advanced material segregation and reuse strategy. Within its operational framework, Flender systematically segregates waste materials, including plastics and metals, which are subsequently reintroduced into production streams—most notably in the manufacturing of components for windmill generators. This process not only reduces the consumption of virgin materials but also significantly contributes to lowering the carbon footprint associated with raw material extraction and processing.

Moreover, the establishment of on-site facilities for sorting and pre-processing recyclable materials enhances operational efficiency while fostering a culture of industrial symbiosis. These initiatives are coherent with the broader objectives of Germany's "Kreislaufwirtschaftsgesetz" (Circular Economy Act), and reflect best practices in industrial resource management.

Hytech Vallée, Grenoble, France – A perfect Systemic Community Thinking Model

Another notable example is the Hytech Vallée, situated in the Grenoble region of France. This innovation-driven industrial cluster has successfully operationalized a Systemic Community Thinking Model that promotes inter-organizational cooperation and collective resource stewardship.

Through this model, participating companies engage in shared logistics arrangements, including communal transportation fleets for both personnel and goods. This has led to marked reductions in vehicular emissions, fuel consumption, and traffic congestion within the industrial zone. The initiative aligns with France's national strategy for ecological transition and circular economy, as outlined in the "Loi relative à la lutte contre le gaspillage et à l'économie circulaire" (AGEC Law).

The Hytech Vallée initiative demonstrates that cooperative frameworks, when underpinned by governance mechanisms and shared digital infrastructure, can optimize both environmental and economic outcomes. The systemic approach adopted here reflects the growing emphasis on cluster-wide circularity as opposed to isolated interventions at the individual firm level.

Slovak Partner – Waste Oil Valorization Initiative

A further example of successful circular implementation is provided by a partner organization based in Slovakia. This entity has established a model for the transformation of waste oils—traditionally a difficult-to-recycle waste stream—into usable oil products through chemical refining and reprocessing techniques.

The initiative addresses both environmental concerns associated with improper disposal of waste oils and the economic opportunity presented by secondary material recovery. The collected waste oil is subjected to a filtration, deacidification, and re-blending process, making it suitable for re-use in specific industrial applications.

This practice resonates with Slovakia's commitment to enhancing circular material use rates as specified in its National Waste Management Programme, and contributes toward achieving compliance with Directive 2008/98/EC on waste and repealing certain directives.

The valorization of hazardous and complex waste streams is a critical area for circular economy progress, and this Slovak initiative stands as a practical and replicable model for regions facing similar waste management challenges.

Austrian Partner – Resource Sharing and Biodiversity Enhancement

An Austrian partner within the ECOLE project has developed a commendable model for integrated resource sharing and ecological enhancement within an industrial setting. This includes the implementation of shared Electric Vehicle (EV) charging infrastructure, which is accessible to multiple tenants within the industrial park. Such shared infrastructure not only reduces the need for redundant installations but also encourages the adoption of sustainable mobility solutions among employees and logistics providers.

In addition to resource sharing, targeted measures have been implemented to promote local biodiversity. These include the creation of green corridors, the installation of pollinator-friendly plant species, and the integration of rainwater harvesting systems that support micro-ecosystems. These initiatives are in harmony with Austria's *Circular Economy Strategy and Biodiversity Strategy 2030*, reflecting an integrated approach that links environmental performance with industrial development.

The Austrian example highlights the importance of embedding environmental considerations not just in production processes but also in spatial and ecological planning within EIPs.

6.2. Lessons Learned from Leading Eco-Industrial Parks

The analysis of the aforementioned case studies reveals several strategic insights and operational lessons essential for the successful implementation of circular economy approaches within Eco-Industrial Parks. A primary lesson is the importance of **integrating sustainability** considerations at the inception stage of industrial park development. As evidenced by the Siemens Technopark in

Ruhstorf, the deliberate incorporation of circularity during the design phase—through infrastructural flexibility, energy-efficient construction, and embedded waste management systems—lays a strong foundation for long-term ecological and economic performance. This underscores the necessity for regulatory frameworks and development guidelines to mandate sustainability criteria as part of initial planning and zoning processes.

Another key takeaway pertains to the critical role of inter-organizational cooperation and resource pooling. The Hytech Vallée in France exemplifies how the adoption of a Systemic Community Thinking Model can generate significant environmental and operational benefits. Through mechanisms such as shared transportation and logistics, participating entities reduce redundancy, lower emissions, and enhance efficiency. These outcomes reinforce the value of fostering cooperative governance structures within industrial clusters, supported by enabling policies and incentives that encourage shared services and mutual resource utilization.

Furthermore, the initiatives undertaken by partners in Slovakia and Austria highlight the effectiveness of targeted material recovery and infrastructure sharing. The Slovak model demonstrates that even complex waste streams, such as used oils, can be successfully valorized into secondary products with appropriate technological interventions and quality control. In Austria, the provision of shared EV charging stations and the implementation of biodiversity-friendly practices illustrate the potential of multipurpose infrastructure to serve both industrial and ecological functions. These practices advocate for policy instruments that incentivize waste-to-resource innovation and nature-positive industrial development.

Lastly, the experience of the Trieste industrial cluster reveals the transformative potential of digital platforms in facilitating industrial symbiosis. By enabling transparent and real-time exchange of raw materials and by-products, such systems enhance the circularity of material flows while ensuring compliance with environmental and safety standards. The integration of digital solutions not only improves material efficiency but also serves as a critical enabler for scaling circular practices across sectors. Accordingly, the promotion of digital infrastructure and data-sharing mechanisms should be considered a cornerstone of future circular economy policy frameworks at both national and European levels.

6.3. Comparative Analysis of Circular Economy Initiatives

Among the circular economy initiatives examined, the industrial parks in Prato (Italy) and Ulsan (South Korea) stand out as established best practice models of eco-industrial parks (EIPs). The Prato 1st Industrial Macrolotto demonstrates successful integration of centralized water recycling, renewable energy through photovoltaic systems, and shared social infrastructure such as an intercompany kindergarten—illustrating a holistic approach to sustainability. Similarly, the Ulsan Industrial Complex (Mipo and Onsan) showcases advanced industrial symbiosis, with extensive by-product exchange systems, energy and water efficiency measures, and strong stakeholder collaboration, making it a benchmark for EIP development globally.

As part of the ECOLE project, a total of ten industrial parks across Europe have been selected as pilot sites to experiment with and implement circular economy and industrial symbiosis strategies. Among these, this report highlights three representative cases that showcase different approaches to enabling circular transition. The Trieste Industrial Zone in Italy focuses on the development of a digital IT tool designed to improve information sharing among companies, laying the groundwork for future resource synergies. Hytech Vallée in France is testing a systemic community-thinking model, incorporating industrial symbiosis and energy management within a multi-sector industrial ecosystem. In Austria, the CRAISS Company industrial park is piloting tangible environmental upgrades such as photovoltaic panels, green noise barriers, and energy-filling stations to enhance energy autonomy and reduce ecological impact. These pilot cases provide valuable insights into the varied pathways industrial parks can take toward circularity, depending on their sectoral composition, local priorities, and technological readiness.

7. Challenges and Barriers

7.1. Financial and Investment Constraints

The transition towards a circular economy (CE) paradigm within the framework of Eco-Industrial Parks (EIPs) represents a significant advancement in aligning industrial development with environmental sustainability and resource efficiency. However, the realization of this vision is frequently impeded by a range of financial and investment-related constraints. These constraints manifest at various stages of project conceptualization, development, implementation, and scaling. Addressing such barriers is critical to enable the systemic shift required for the sustainable transformation of industrial zones.

A key impediment to the implementation of circular economy initiatives in EIPs is the limited availability of upfront capital necessary to finance technological upgrades, infrastructure modifications, and system-wide process redesigns. Circular interventions such as industrial symbiosis, resource valorisation, renewable energy integration, and waste minimization technologies often necessitate significant initial investment with delayed financial returns.

Small and medium-sized enterprises (SMEs), which typically constitute a considerable share of EIP tenants, are disproportionately affected by this constraint due to constrained liquidity and restricted credit access. Financial institutions often perceive CE projects as high-risk due to their complex interdependencies, limited track record, and uncertain return on investment (ROI) timelines. Consequently, industrial actors are frequently unable to secure loans or credit lines on favourable terms, inhibiting the adoption of CE strategies.

The absence or insufficiency of tailored financial instruments and incentive mechanisms tailored to the specificities of EIPs acts as a further disincentive to investment. Conventional financing models are predominantly linear in orientation and fail to recognize the long-term resource efficiency gains, environmental externalities, and socio-economic co-benefits associated with circular practices.

Current public funding mechanisms, where available, often entail complex administrative procedures and stringent eligibility criteria that dissuade participation from smaller actors. Moreover, subsidies and tax incentives continue to favour linear models in many jurisdictions, thereby creating a market distortion that undermines the competitiveness of CE-aligned investments. The lack of green financing tools—such as sustainability-linked loans, circular economy bonds, and blended finance schemes—constrains the mobilization of capital towards regenerative business models.

Another significant constraint lies in the limited institutional capacity among EIP management bodies and local authorities to design bankable CE projects and effectively interface with financial markets. The development of CE initiatives requires a nuanced understanding of financial engineering, including life-cycle costing, impact assessment, risk mitigation strategies, and innovative procurement models.

In many regions, institutional actors lack the requisite technical expertise and human resource capacity to structure projects in a manner that aligns with investor expectations and due diligence requirements. This gap results in a sub-optimal project pipeline and missed opportunities for accessing climate finance, green development funds, or international donor support. Moreover, the lack of coordination between industrial policy and financial regulation further impedes the integration of CE considerations into regional economic development planning.

Financial and investment constraints present a multifaceted challenge to the effective implementation of circular economy strategies in Eco-Industrial Parks. Addressing these constraints necessitates a coordinated approach involving policy reform, financial innovation, capacity development, and institutional strengthening. By fostering an enabling environment that reduces perceived investment risks, aligns stakeholder incentives, and promotes long-term value creation, it is possible to unlock the capital flows required to support a resilient, resource-efficient, and circular industrial transition.

7.2. Technological Limitations

The integration of circular economy (CE) principles into the operational frameworks of Eco-Industrial Parks (EIPs) relies heavily on the availability, accessibility, and adaptability of appropriate technological solutions. These technologies span across various domains, including material recovery, waste valorisation, renewable energy systems, resource efficiency tools, and digital monitoring platforms. Despite the growing body of innovation in CE-related technologies, several limitations continue to restrict their deployment, scalability, and effectiveness within EIP contexts.

These technological constraints significantly hinder the realization of circular synergies, thereby impeding the overall transition to sustainable industrial ecosystems.

One of the predominant challenges is the limited availability of mature and commercially scalable circular technologies suited for application within diverse industrial clusters. While numerous CE technologies are under development or piloted in academic and research settings, many have not yet reached a technology readiness level (TRL) sufficient for large-scale, real-world deployment. Technologies for advanced waste processing, chemical recycling, industrial symbiosis facilitation, or bio-based material production often remain in the demonstration phase, constrained by unproven performance under variable operational conditions.

The absence of robust performance data, particularly across different industrial sectors and climatic conditions, further disincentivizes adoption. Consequently, EIP tenants and operators are reluctant to invest in untested technologies, especially when such investments may disrupt existing processes or entail significant downtime. The lack of proven replicability, interoperability, and integration capability across industrial systems exacerbates this limitation.

Circular economy implementation in EIPs inherently requires interconnected systems capable of exchanging materials, energy, water, and information. However, the existing technological infrastructure within many industrial parks is not designed for cross-sectoral integration or symbiotic operations. The heterogeneity of industrial processes, proprietary technologies, and legacy systems often leads to incompatibility issues that hinder the technical feasibility of resource-sharing arrangements.

A key enabler of circular economy within EIPs is the effective use of digital technologies, including the Internet of Things (IoT), artificial intelligence (AI), digital twins, and material flow analytics. These technologies facilitate the identification of resource synergies, track material lifecycles, optimize process efficiency, and support predictive maintenance. However, the deployment of such digital infrastructure remains limited due to cost, technical complexity, and data governance challenges.

Many industrial parks, particularly in emerging economies, lack the basic ICT infrastructure required for real-time data collection and analysis. Moreover, there is often a low level of digital literacy among staff, limiting the effective use of advanced monitoring tools. Concerns over data confidentiality, cyber security, and intellectual property rights also inhibit information sharing between firms, which is critical for enabling industrial symbiosis. The absence of centralized data platforms and interoperability standards further impairs collaborative decision-making and system-wide optimization.

Rapid technological advancement poses a dual challenge: while it provides opportunities for innovation, it also risks rendering current investments obsolete. This dynamic creates uncertainty for industrial actors who are reluctant to commit capital to technologies that may soon be outdated. Additionally, the adoption of proprietary technologies can result in vendor lock-in, limiting the flexibility of EIP participants to switch to more sustainable or cost-effective alternatives in the future.

In contexts where regulatory frameworks are evolving, and market preferences are shifting, the risk of technological obsolescence acts as a barrier to early adoption. Without mechanisms for future-proofing technological investments—such as modular design, open-source platforms, or performance-based procurement—industries may default to maintaining the status quo.

Technological limitations present complex and interrelated barriers to the effective implementation of circular economy principles in Eco-Industrial Parks. These constraints span across the entire technology lifecycle—from research and development to deployment, integration, and long-term maintenance. Overcoming these barriers necessitates a coordinated and multi-level approach, involving strategic investments in research and innovation, capacity building, digital infrastructure, and public-private partnerships. Moreover, the development of enabling regulatory frameworks, standardization protocols, and sector-specific guidance is essential to foster a conducive environment for CE technology adoption in EIPs. Without addressing these technological limitations, the systemic transformation envisioned under the circular economy model will remain constrained in scope, scale, and impact.

7.3. Stakeholder Engagement and Collaboration Challenges

The circular economy (CE) paradigm, particularly within the context of Eco-Industrial Parks (EIPs), is fundamentally predicated on systemic cooperation and coordinated action among a diverse array of stakeholders. These include, but are not limited to, industrial enterprises, park operators, local and regional authorities, utility providers, research institutions, civil society organizations, and financial entities. The successful implementation of CE principles such as industrial symbiosis, resource efficiency, and shared infrastructure—necessitates high levels of trust, communication, and shared vision across these actors.

However, in practice, achieving such multilateral engagement is fraught with challenges. A variety of institutional, cultural, operational, and governance-related factors hinder the effective alignment of interests, responsibilities, and incentives necessary for sustained collaboration. These challenges significantly impede the co-creation, deployment, and scaling of circular solutions in EIPs.

One of the most pervasive barriers to stakeholder engagement in EIPs is the inherent divergence in the objectives and priorities of different actors. While policymakers may prioritize environmental outcomes, businesses often focus on economic viability and operational efficiency. This misalignment can create conflict in the planning and implementation phases of CE initiatives.

For example, the adoption of industrial symbiosis may offer long-term environmental and economic benefits but could entail short-term disruptions and additional costs for individual firms. In the absence of equitable cost-benefit sharing mechanisms, firms may resist collaboration. Similarly, local authorities may lack the mandate or motivation to facilitate CE projects if they do not result in immediate public benefits or political capital.

Trust is a prerequisite for any form of collaboration, particularly in contexts that require the exchange of information, materials, or infrastructure. In EIPs, where firms are often competitors or operate in unrelated sectors, trust deficits can pose a serious challenge to stakeholder cooperation.

Concerns regarding confidentiality, intellectual property rights, and misuse of shared data are common and frequently deter open communication. Moreover, differences in organizational culture, management styles, and decision-making processes can lead to misunderstandings and reluctance to engage in joint initiatives.

These trust and cultural barriers are often exacerbated in industrial parks comprising multinational companies, small and medium enterprises (SMEs), and public institutions with varying degrees of capacity, language proficiency, and institutional memory. In such heterogeneous environments, developing a common collaborative culture requires deliberate and sustained facilitation, which is frequently lacking.

The implementation of CE strategies in EIPs often fails due to the absence of dedicated institutional mechanisms for coordination and facilitation. Unlike linear models that operate within firm-level boundaries, circular models demand cross-organizational planning and execution. However, most EIPs lack a neutral coordinating body equipped with the mandate, technical knowledge, and facilitation skills required to harmonize multi-stakeholder efforts.

Without a dedicated CE facilitator or park-level governance mechanism, stakeholder engagement remains ad hoc, personality-driven, or limited to project-specific contexts. This results in inefficiencies, duplication of efforts, and an inability to institutionalize successful practices. Moreover, the lack of formal platforms for regular dialogue and knowledge exchange inhibits the building of long-term partnerships.

CE implementation requires long-term commitment, but many stakeholder partnerships in EIPs are project-based, driven by short funding cycles or temporary mandates. As a result, once a project ends, so do the collaborative mechanisms established under its purview. This discontinuity undermines the institutional memory, trust, and momentum necessary for sustained CE transitions.

Furthermore, the lack of follow-up funding or continuity plans prevents the scaling or replication of successful pilot initiatives. Developing durable institutional structures, embedding CE objectives into long-term park management plans, and aligning funding mechanisms with systemic transformation goals are essential to mitigate this challenge.

7.4. Regulatory and Bureaucratic Hurdles

The effective implementation of circular economy (CE) principles within Eco-Industrial Parks (EIPs) requires a robust, coherent, and enabling regulatory framework. Such a framework must facilitate resource efficiency, support industrial symbiosis, and promote the valorisation of secondary raw materials across sectors. However, in practice, existing regulatory and administrative systems often fall short of supporting the complex and integrated processes that CE strategies entail. Instead, they frequently act as impediments due to fragmentation, inconsistency, and procedural rigidity.

Regulatory and bureaucratic hurdles are among the most critical structural barriers that limit the operationalization of circular models in EIPs. These challenges manifest in various forms, including outdated legal definitions, overlapping institutional mandates, rigid permitting procedures, and insufficient policy integration. The cumulative effect is a regulatory environment that discourages innovation, impedes cross-sectoral collaboration, and increases compliance burdens for firms seeking to transition to circular practices.

One of the most persistent regulatory barriers in CE implementation is the lack of clear and harmonized legal definitions concerning waste, by-products, and secondary raw materials. In many jurisdictions, materials intended for reuse or recycling are still legally classified as "waste," thereby subjecting them to stringent regulations that are not designed for resource circulation.

This misclassification often results in unnecessary compliance obligations, such as licensing, transport documentation, and treatment standards, even when the materials pose no significant environmental or health risks. As a consequence, firms are disincentivized from engaging in material exchange or valorisation, undermining the very foundation of industrial symbiosis within EIPs.

Furthermore, inconsistent interpretations of regulatory terms across local and national agencies create legal uncertainty and operational delays. Without harmonized and science-based definitions, the regulatory system remains a barrier rather than an enabler of circular flows.

Another significant challenge is the complexity and duration of environmental and operational permitting procedures, particularly when circular activities involve multiple sectors or cross-cutting processes. For example, projects that seek to utilize waste heat, co-process by-products, or establish joint treatment facilities often require multiple approvals from various regulatory bodies, including environmental agencies, industrial safety departments, and municipal authorities.

These processes are often not streamlined, and they may lack standardized timelines or clear criteria for approval. The absence of integrated permit schemes for circular initiatives leads to excessive administrative burdens, higher transaction costs, and prolonged delays in project implementation. For SMEs in particular, the procedural complexity can act as a de facto exclusion mechanism.

Moreover, permitting procedures rarely accommodate the dynamic nature of CE operations, such as adaptive reuse, modular production, or cascading use of resources. Regulatory systems built around static, linear models struggle to accommodate such flexible approaches, thereby restricting innovation.

Looking at a Bureaucracy; Multiple layers of bureaucracy, coupled with unclear mandates and poor inter-agency coordination, further exacerbate regulatory and administrative challenges. In many cases, the implementation of CE-related projects requires interaction with diverse public authorities—such as environmental agencies, trade departments, utility regulators, and municipal planning offices—each with distinct procedures, objectives, and timelines.

The absence of a centralized or designated CE authority results in disjointed decision-making and a lack of accountability. For EIP operators and businesses, this institutional complexity leads to higher compliance costs, administrative fatigue, and reluctance to pursue circular ventures. It also creates inconsistent regulatory outcomes, depending on the discretion and interpretation of individual officials.

Efforts to streamline bureaucratic procedures, clarify institutional responsibilities, and establish one-stop coordination mechanisms remain limited and insufficiently funded in most regions.

Regulatory and bureaucratic hurdles represent foundational impediments to the successful deployment of circular economy approaches within Eco-Industrial Parks. The current regulatory environment, marked by outdated classifications, fragmented governance, rigid procedures, and limited innovation allowances, is ill-suited to support the systemic changes that CE demands. Addressing these challenges requires targeted regulatory reforms, enhanced inter-agency coordination, legal modernization, and the creation of enabling environments that support experimentation, collaboration, and long-term investment. Without such structural transformation, the promise of circularity in industrial ecosystems will remain constrained by legal and administrative inertia.

8. Monitoring and Evaluation Metrics

8.1. Key Performance Indicators (KPIs) for Circular Economy in EIPs

The operationalization of circular economy (CE) principles within Eco-Industrial Parks (EIPs) requires robust monitoring and evaluation frameworks that are informed by precise, measurable, and policy-aligned indicators. To ensure that the transition towards circularity in EIPs is both systematic and scalable, the development and implementation of Key Performance Indicators (KPIs) is of paramount importance. These KPIs serve as quantitative and qualitative benchmarks for assessing progress, identifying gaps, and facilitating data-driven decision-making for industrial symbiosis, resource efficiency, and environmental compliance.

The application of KPIs in the context of EIPs should align with existing regulatory instruments, national circular economy roadmaps, sustainable development goals (SDGs), and industrial ecology principles. Moreover, KPIs must be harmonized across stakeholders—including park operators, tenant industries, local authorities, and environmental regulators—to ensure consistency in data collection, interpretation, and reporting.

Following can be the Illustration of Key Performance Indicator

KPI Category	Indicator	Unit of Measurement	Measurement Frequency	Responsible Entity
Resource Efficiency	Material input per unit of product	kg/unit product	Quarterly	Park Operator, Industries
	Energy intensity per production output	kWh/unit output	Quarterly	Energy Manager, Industries
	Water consumption per process	m^3/process	Quarterly	Environmental Unit
Waste and Emissions	Hazardous waste generated per year	tonnes/year	Annually	Environmental Regulator
	Recycling rate of solid waste	% of total waste	Semi-annually	Waste Management Authority

KPI Category	Indicator	Unit of Measurement	Measurement Frequency	Responsible Entity
	GHG emissions per unit of production	kg CO_2/unit output	Annually	Industry Compliance Officer
Circular Business Models	% of businesses engaged in industrial symbiosis	% of total tenant industries	Annually	EIP Management Committee
	Rate of product/service reuse or remanufacturing	% of products reused/remanufactured	Semi-annually	Park Administration
Economic Impact	Cost savings from circular strategies	EUR/year	Annually	Financial Controllers
	Revenue generated from secondary raw materials	EUR/year	Annually	Finance Department
Social and Institutional	No. of employees trained in circular economy practices	Number/year	Annually	HR/Training Department
	Stakeholder engagement sessions conducted	Number/year	Biannually	Park Governance Board
Innovation and R&D	Investment in circular economy-related R&D	EUR/year	Annually	Innovation Office
	No. of collaborative projects with external partners	Number/year	Annually	Park Innovation Hub

In order to mainstream KPIs into the governance of EIPs, alignment with national and regional legal instruments is essential. This includes:

- Compliance with national environmental protection laws

- Conformance with European Union directives on circular economy, waste, and emissions
- Harmonization with ISO standards such as ISO 14001 (Environmental Management Systems) and ISO 14051 (Material Flow Cost Accounting)

Governments may further incentivize the use of KPIs by linking them to eligibility for public subsidies, tax benefits, or preferential access to industrial land and infrastructure.

The establishment of well-defined Key Performance Indicators is a cornerstone for the successful implementation of circular economy approaches within Eco-Industrial Parks.

8.2. Lifecycle Assessment Techniques

The integration of Lifecycle Assessment (LCA) techniques within Eco-Industrial Parks (EIPs) constitutes a fundamental component of the analytical toolkit required to evaluate and guide the implementation of circular economy (CE) strategies. LCA provides a science-based, systematic framework for assessing the environmental impacts associated with all stages of a products or system's life—from raw material extraction through production, use, and end-of-life management. In the context of EIPs, where industrial symbiosis, resource optimisation, and closed-loop systems are foundational principles, LCA enables informed decision-making, facilitates benchmarking, and ensures alignment with environmental and sustainability objectives.

Lifecycle Assessment serves several essential functions in the operationalisation of circular economy principles in EIPs:

- Environmental Performance Evaluation
- Comparative Analysis
- Support for Industrial Symbiosis
- Policy and Compliance Monitoring
- Innovation and Eco-design

Lifecycle Assessment within EIPs shall be conducted in accordance with internationally recognised standards, particularly the ISO 14040 and ISO 14044 series. The methodology typically involves the following four phases:

- Goal and Scope Definition: This phase clarifies the purpose of the assessment, the system boundaries (e.g., gate-to-gate, cradle-to-grave), and the functional unit used for quantifying results. In the EIP context, the scope may include multiple interconnected processes and shared infrastructure.
- Life Cycle Inventory (LCI) Analysis: This phase involves the collection and quantification of input and output data related to energy, materials, emissions, and waste. Due to the complexity of EIP networks, data may be sourced from multiple tenant industries, central utilities, and external partners.
- Life Cycle Impact Assessment (LCIA): In this stage, inventory data is translated into environmental impact categories such as global warming potential, eutrophication, acidification, resource depletion, and human toxicity. It is essential that impact assessment models be context-specific and regionally calibrated where applicable.
- Interpretation: The results are analysed to draw conclusions, identify key contributors to environmental impacts, and recommend improvements. This phase includes sensitivity analysis, uncertainty quantification, and validation of assumptions.

Lifecycle Assessment methodologies deployed in EIPs should be harmonised with broader international and national policy frameworks, including the European Green Deal and Circular Economy Action Plan (CEAP), United Nations Sustainable Development Goals with No. 9,12, and 13, The EU taxonomy for sustainable Activities, ISO 14001 (Environmental Management System), GHG Protocol and Environmental Product Declaration.

8.3. Reporting and Transparency Guidelines

Transparent and timely reporting is a cornerstone of effective circular economy (CE) governance within Eco-Industrial Parks (EIPs). Establishing clear reporting and disclosure protocols ensures that all stakeholders ranging from regulatory authorities and park operators to tenant industries and the public have access to consistent, verifiable, and actionable information. Such transparency reinforces accountability, supports compliance with environmental legislation, and builds trust in the circular economy transition process.

Reporting frameworks in EIPs should be aligned with international sustainability disclosure standards such as the Global Reporting Initiative (GRI), the EU Corporate Sustainability Reporting Directive (CSRD), and national-level environmental and industrial development policies. Reports must be submitted at regular intervals (typically annually or semi-annually) and should encompass a comprehensive set of indicators, including resource consumption, waste generation, emissions, industrial symbiosis activities, and lifecycle assessment results. In addition, disclosures must include a narrative component detailing progress toward CE goals, challenges encountered, and corrective actions undertaken.

To facilitate comparability and reduce administrative burdens, EIPs are encouraged to adopt standardized reporting templates and digital platforms for data submission. These systems should support automated data integration from tenant operations, real-time tracking of key performance indicators (KPIs), and access to dashboards for internal and external review. Where possible, third-party verification of reported data should be undertaken to enhance credibility and ensure alignment with applicable environmental regulations and CE benchmarks.

It is imperative that reporting obligations are embedded within the legal or contractual framework governing the EIP. This may take the form of regulatory mandates, lease agreements, or eligibility criteria for financial incentives. Park authorities must also ensure that tenants are adequately informed of their reporting responsibilities and are provided with technical support to fulfil them. Non-compliance mechanisms, including penalties or the withholding of park services, may be instituted to ensure participation and data integrity.

In fostering a culture of transparency, EIPs are positioned not only to monitor progress internally but also to serve as demonstrative models of sustainable industrial development. Public disclosure of sustainability performance, when done systematically and credibly, can attract green investment, enhance competitiveness, and reinforce the EIP’s contribution to national and global circular economy objectives.

9. Roadmap for Future Implementation

9.1. Emerging Trends in Circular Economy for Industrial Parks

In the evolving landscape of sustainable development, the operationalization of circular economy (CE) principles within industrial ecosystems has garnered increased relevance. Eco-Industrial Parks (EIPs), as defined by the United Nations Industrial Development Organization (UNIDO), are industrial parks in which businesses cooperate with each other and with the local community to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural habitat), and achieve sustainable development, with the intention of increasing economic gains and improving environmental quality. Within this context, the incorporation of emerging circular economy trends has become pivotal to transitioning from linear production systems toward regenerative and resilient industrial configurations.

A key emerging enabler of circular practices in industrial parks is the application of digital technologies. The integration of digital platforms—such as Industrial Internet of Things (IIoT), Artificial Intelligence (AI), and blockchain—facilitates enhanced monitoring, tracing, and optimisation of resource flows.

Data-driven tools are increasingly being employed to support life-cycle assessments, real-time emissions monitoring, and predictive maintenance, thereby enabling industries to reduce resource input and waste output. Smart material passports and digital twins are being developed to track the quality and history of materials, particularly in manufacturing and construction sectors. These tools allow for the systematic identification of secondary resource opportunities and facilitate reverse logistics within the park ecosystem.

Public authorities are beginning to recognize the need for standardized digital protocols and interoperable data systems to ensure trust, transparency, and scalability. In the European context, initiatives under the Digital Europe Programme and European Data Strategy signal a clear direction toward harmonizing digital infrastructures with sustainability imperatives. In future implementation roadmaps, digital readiness must be considered a fundamental prerequisite for CE integration in EIPs.

Innovative business models rooted in circularity are gaining traction within industrial parks. These models—such as Product-as-a-Service (PaaS), resource recovery, and shared manufacturing—promote material decoupling from economic growth. In particular, the emergence of industrial symbiosis networks within EIPs facilitates the reuse of waste streams from one entity as input for another, thereby creating circular value chains at the meso level.

Governments are increasingly leveraging Extended Producer Responsibility (EPR) schemes to align private sector incentives with material stewardship goals. By holding producers accountable for the post-consumer phase of their products, EPR mechanisms stimulate the design of more durable, repairable, and recyclable goods. EIPs serve as practical testbeds for such models, allowing for coordinated implementation among geographically proximate actors.

Another prominent trend is the decentralization of utility services to enhance circularity. Distributed renewable energy generation (e.g., solar microgrids, bioenergy systems), decentralized wastewater treatment, and modular material recovery facilities are being deployed within EIPs to enable autonomous resource management.

These infrastructures are often designed for adaptability and scalability, allowing for dynamic adjustment of resource flows based on demand and supply variability. For instance, waste heat from one industry may be captured and redistributed through a localized district heating network, or greywater may be treated on-site and reused for non-potable purposes.

The transition toward circular economy implementation in industrial parks necessitates significant investments in workforce upskilling and reskilling. Emerging circular operations—such as disassembly, remanufacturing, materials testing, and waste valorization—require specific technical and managerial competencies that are often underdeveloped in traditional industrial contexts.

Education and training systems must evolve to include circular economy principles at all levels, from vocational training to higher education. Public-private partnerships within EIPs can facilitate knowledge exchange, pilot programs, and continuous learning ecosystems.

Future implementation strategies should include capacity-building targets and establish CE learning hubs within or adjacent to EIPs. The inclusion of labor market indicators in CE monitoring frameworks will be essential for tracking progress and identifying skill gaps.

9.2. Policy Recommendations and Stakeholder Engagement Strategies

The successful implementation and long-term institutionalization of circular economy (CE) approaches within Eco-Industrial Parks (EIPs) necessitate robust policy frameworks and inclusive stakeholder engagement mechanisms. As industrial systems evolve in response to environmental imperatives and economic transitions, policymakers are required to enact strategic interventions that address systemic challenges while fostering innovation, cross-sector collaboration, and socio-economic inclusivity.

We have divided these comprehensive set of policy recommendations and engagement strategies into 5 inter-related domains i.e., Governance and Stakeholder Collaboration, Innovation and Digitalization, Financial and Policy Support, Circular Economy and Sustainability strategies and Scalability and Replicability.

Governance and Stakeholder Collaboration

A sound governance structure is foundational for the effective orchestration of circular economy initiatives in EIPs. It ensures accountability, strategic alignment, and continuous improvement across multiple industrial actors and regulatory interfaces.

Establish a Dedicated Governance Body: To steer and coordinate CE implementation efforts at the park level, it is recommended to constitute a dedicated EIP Governance Body. This entity should be mandated with regulatory oversight, strategic planning, performance monitoring, and facilitation of stakeholder dialogue. The body must operate with legal recognition and institutional autonomy, enabling it to mediate across governmental, private sector, and civil society actors.

Encourage Multi-Stakeholder Engagement: Multi-stakeholder engagement is essential for the legitimacy and inclusiveness of CE transitions. Mechanisms such as stakeholder roundtables, joint planning committees, and sectoral working groups should be institutionalized. These platforms will enable knowledge exchange, co-development of circular solutions, and participatory decision-making. Engagement must extend beyond industry actors to include local authorities, research institutions, non-governmental organizations, and affected communities.

Develop a Systemic Thinking Community Model: The establishment of a **systemic thinking community model** is recommended to cultivate a shared vision among stakeholders. This model should promote systems thinking methodologies, scenario planning, and cross-disciplinary learning to build collective capacity in understanding and managing complex CE transitions. It should be embedded within local innovation ecosystems and linked to broader regional and national circular economy platforms.

Innovation and Digitalization

Innovation and digital tools serve as catalysts for accelerating CE implementation by enhancing efficiency, enabling data-driven decision-making, and unlocking new business models.

Implementation of Cost-Benefit and Multi-Criteria Analysis Tools: The development and deployment of **cost-benefit analysis (CBA)** and **multi-criteria analysis (MCA)** tools are critical to support evidence-based policy and investment decisions in EIPs. These tools should integrate environmental, economic, and social indicators, and be calibrated to assess the feasibility, impact, and scalability of circular interventions. Regulatory authorities may mandate the use of such tools as part of project approval processes and public funding evaluations.

Additionally, such tools should be made accessible to EIP operators and investors through open digital platforms or integrated into regional planning instruments. Capacity-building measures should accompany the roll-out of these tools to ensure their effective utilization.

Financial and Policy Support

Targeted financial mechanisms and enabling policy frameworks are indispensable for mobilizing investments and aligning EIP development with broader sustainability objectives.

Align EIP Development with the EU Green Deal and CE Action Plan: Member States and affiliated regions are encouraged to integrate EIP initiatives within the strategic frameworks of the European Green Deal, the EU Circular Economy Action Plan, and the Industrial Strategy for a Green and Digital Europe. This alignment will enhance policy coherence, facilitate access to EU funding programmes, and ensure that national actions contribute to EU-wide climate neutrality and resource efficiency targets.

Develop Financial Incentives for CE Initiatives: Governments should develop and operationalize financial incentives aimed at stimulating CE-related investments within EIPs. Recommended instruments include tax credits for resource-efficient technologies, depreciation allowances for circular assets, performance-based subsidies, and preferential loan schemes. Public-private partnership models can also be structured to share investment risks and returns for high-impact CE projects.

Regulatory frameworks must be updated to formally recognize CE business models, thereby enabling access to green finance instruments and environmental credit systems. Clear eligibility criteria and reporting standards should be established to safeguard transparency and accountability.

Circular Economy and Sustainability Strategies

Mainstreaming circular economy strategies into industrial operations requires structural transformations in production processes, business relationships, and resource flows.

Encourage Industrial Symbiosis: Policymakers should actively promote industrial symbiosis (IS) as a key strategy for realizing circularity at the meso level. This includes the facilitation of resource-sharing networks, by-product exchanges, and utility co-usage among co-located firms. Regulatory authorities may establish IS facilitation centers within EIPs, which can serve as intermediaries for matchmaking, feasibility assessments, and compliance monitoring.

Furthermore, zoning regulations and park planning guidelines should be revised to priorities co-location of synergistic industries and enable physical infrastructure sharing (e.g., steam lines, water recycling systems).

Adopt Circular Economy Principles: All industrial activities within EIPs should progressively align with CE principles such as design for longevity, waste prevention, resource circularity, and regenerative operations. Regulatory agencies may issue CE compliance guidelines and benchmarks for industrial operations, supplemented by certification schemes that reward exemplary circular performers.

Environmental Impact Assessment (EIA) protocols should be amended to include CE considerations as core criteria for industrial project approvals and operational licensing.

Scalability and Replicability

For the circular economy transition to generate systemic impact, policy and practice must be designed for replicability and scalability across diverse industrial geographies.

Develop Standardized KPI Framework: A standardized Key Performance Indicator (KPI) framework should be developed at the national or EU level to evaluate the circularity performance of EIPs. KPIs should encompass quantitative and qualitative metrics across resource use, emissions, waste generation, innovation uptake, and social impact. This framework should be integrated with monitoring and reporting obligations under environmental and industrial policy instruments.

To ensure consistent application, technical guidelines, toolkits, and capacity-building measures should accompany KPI roll-out. Benchmarking mechanisms and recognition schemes can further stimulate healthy competition and knowledge sharing among EIPs.

Create a Roadmap for EIP Transition: Finally, the formulation of a national or regional roadmap for EIP transition is recommended to provide a structured pathway toward CE implementation. The roadmap should outline targets, milestones, responsibilities, and resource allocations across the short, medium, and long term. It must be developed through an inclusive, consultative process and subject to periodic review based on monitoring outcomes and stakeholder feedback.

Such a roadmap must also ensure horizontal integration with broader environmental, energy, urban development, and labour policies, thereby embedding CE considerations within the mainstream policy apparatus.

9.3. Future Research and Development Directions

The transformation of industrial parks into regenerative and resource-efficient systems is contingent upon a sustained commitment to research and development (R&D). While foundational frameworks for circular economy (CE) implementation in Eco-Industrial Parks (EIPs) have been established, a number of technological, regulatory, and systemic uncertainties persist. These require targeted research interventions, interdisciplinary collaboration, and long-term innovation strategies.

With the shift from Linear to Circular models in Industrial Parks; It involves complex interdependencies across materials, energy, institutions, and behavioral systems. That’s why Systems-based research on Circular industrial Transition becomes important and where R&D

should focus on **Dynamic systems modelling** to, **material flow and energy flow analysis** at park level to understand the trade-offs and synergies, Scenario planning and foresight studies.

Looking at Innovation in secondary resource valorization, R&D can be focused on **Development of low-energy, high efficiency separation technologies** for complex materials, **bio based and bio-degradable alternatives**, Industrial Pre-treatment and **post-consumer waste recovery**, **Remanufacturing and refurbishment techniques**. In addition to that looking into digital Twin and predictive intelligence for EIPs; **Integration of sensors network** and **IoT technologies**, **Predictive analytics** and **AI-based tools**, Block-chains enabled with traceability systems. The main problem with this digital technology is the method of communication between these sensors, and technologies which needs to be regulated, standardized and need to make it secure.

10. Conclusion

10.1. Summary of Key Findings

The project has made substantial progress in advancing awareness and fostering acceptance of circularity principles across diverse stakeholder groups. This was achieved by adopting a systemic Community Thinking Model, which effectively facilitated inclusive engagement and collaborative action. The model served as a robust framework for aligning stakeholder interests, encouraging dialogue, and nurturing shared responsibility towards circular transitions.

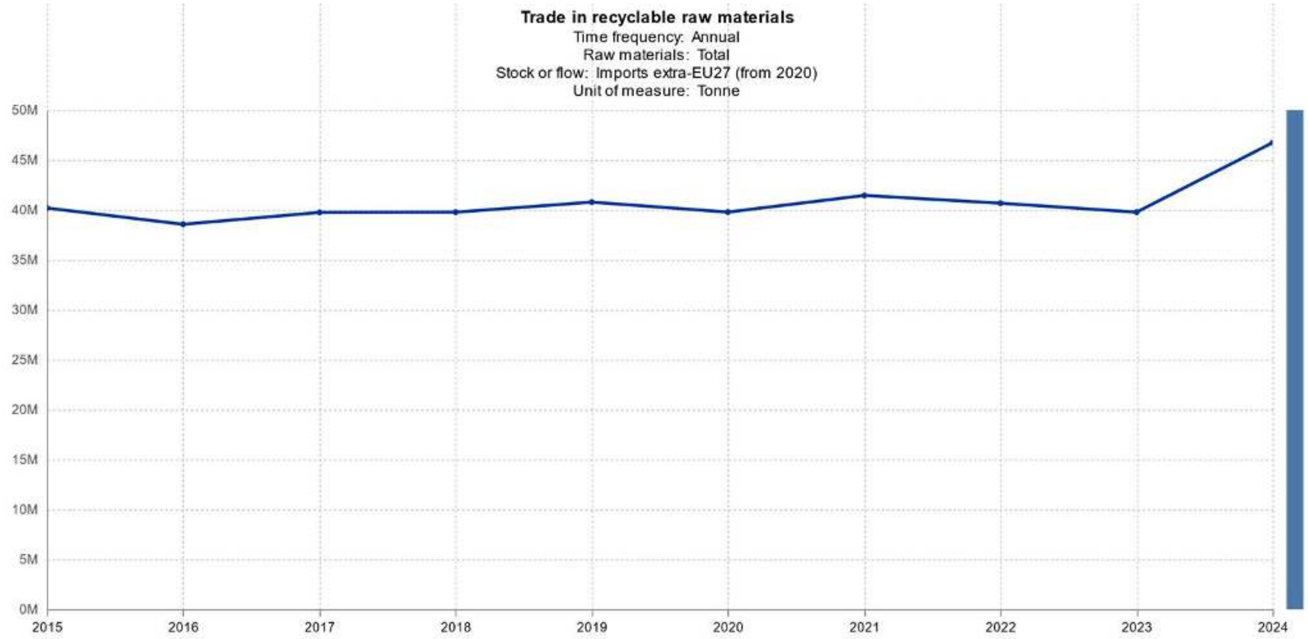
A demonstrative success of these efforts can be observed in several European eco-industrial parks, notably those located in France, Italy, and Germany. These cases exemplify the practical applicability of the Community Thinking Model, showcasing how collaborative initiatives can lead to meaningful change at the industrial level.

Throughout the course of the project, several encouraging outcomes have been recorded. These include an increasing willingness among industrial actors to enhance operational efficiency, explore and integrate renewable energy solutions, and embrace the transformation of waste into valuable resources. Additionally, the emergence of resource-sharing mechanisms—ranging from shared transportation logistics and communal use of raw materials to the redistribution of waste by-products across business networks—marks a significant step towards industrial symbiosis.

However, while the results to date are promising, they remain insufficient when assessed against the scale of transformation required. To achieve lasting impact and enable the systemic shift from a linear to a circular economy, such efforts must be both replicated and scaled up. Broadening the reach and depth of these initiatives is essential to establish a resilient, resource-efficient, and sustainable industrial ecosystem for the future.

10.2. Final Thoughts on Scaling Circular Economy in EIPs

The transition towards a circular economy within Eco-Industrial Parks (EIPs) has entered a critical phase where the outcomes of initial policy and infrastructural efforts are becoming increasingly visible. According to the most recent Eurostat data on trade in raw materials, there has been a marked **increase of approximately 17.5% in circular trade activity** over the past year alone. This notable uptick provides a clear indication that the foundational strategies laid in support of circular practices are beginning to yield measurable progress.



Moreover, the financial dimension of the circular economy is gaining significant momentum. Forecasts from leading financial institutions now estimate that the market value of the circular economy within the European Union **may reach €100 billion by 2030**, a substantial rise from the current valuation of €31 billion. This surge reflects **growing investor confidence and institutional recognition of the long-term economic and environmental benefits** of circular systems.

Nevertheless, despite these encouraging developments, the current pace of transformation remains insufficient when considered in light of the magnitude of global waste generation. For instance, the global fashion industry alone is responsible for discarding an estimated 40 million tonnes of waste every second, a staggering figure that starkly contrasts with the EU's annual recycling capacity of approximately 47 million tonnes, even after factoring in the recent 17.5% increase. These statistics highlight a critical disparity between progress achieved and the scale of the challenge that remains.

Therefore, while **existing efforts have established a positive trajectory, they must be intensified and scaled across industrial sectors to ensure sustainable, long-term outcomes**. The goal of achieving at least 50% recyclability in the coming years is both necessary and attainable, provided that supportive regulatory frameworks, sustained financial investment, and cross-sectoral collaboration continue to advance in a cohesive manner.

In summary, the foundation for circular economy integration within EIPs has been successfully established, and early indicators are promising. However, **persistent enhancement of systemic capacity, policy enforcement, and innovation uptake will be essential** to transform these preliminary gains into comprehensive and enduring results.