WHITE PAPER

Industrial symbiosis as a catalyst for sustainable SEZ development

Aligning with UNIDO eco-industrial park principles

Targeting special economic zones (SEZ) policymakers & developers in the Middle East and North Africa (MENA)

FEV energy + resources and NurZen

August 2026

Executive summary

Industrial symbiosis as a catalyst for sustainable SEZ development

3.2 Mt CO_2/yr

Emissions reduction potential
Full industrial symbiosis + technology integration

Up to €4bn/yr

OPEX savings potential
Representative industrial park

3–10 yr payback

Return on CAPEX
~€2.4bn technology investment

Special economic zones (SEZs) and industrial parks across the MENA region are at a defining inflection point. Historically valued as low-cost manufacturing platforms, these zones are now subject to rigorous environmental, social, and governance (ESG) screening by investors, sovereign wealth funds, and development finance institutions. Green finance is no longer a premium option; it has become a prerequisite for attracting capital, securing anchor tenants, and accessing sustainability-indexed funds.

Industrial symbiosis defined as the collaborative exchange of energy, materials, and by-products between co-located industries, is now the single most effective mechanism for transforming a conventional industrial park into a globally competitive, ESG-compliant eco-industrial park (EIP). Critically, industrial symbiosis also builds zone resilience by reducing reliance on external energy and raw material imports; zones become structurally more robust to geopolitical disruption, commodity price shocks, and climate-related supply chain risk.

FEV's industrial symbiosis model — features and benefits

Benefit pillar	What FEV's industrial symbiosis model delivers
Commercial	Up to €4bn/yr in operating cost (OPEX) savings from waste heat recovery, shared utilities, and by-product valorisation. ~€2.4bn technology capital expenditure (CAPEX) with a payback period of 3–10 years, depending on park configuration. Industrial symbiosis participation generates new revenue streams for zone operators through energy and resource trading.
Resilience	Reduced dependency on external energy and raw material imports, insulating zones from commodity price volatility. Sensitivity analysis confirms financial robustness against ±20% electricity and ±30% gas price swings. Modular public-private partnership (PPP) structure allows phased deployment, reducing upfront risk for zone authorities and private investors.
Sustainability	Up to 3.2 Mt CO_2 reduction per year under full industrial symbiosis deployment, which is equivalent to removing 700,000+ cars from the road. Closed-loop water and material cycles reduce waste-to-landfill by >80%, supporting UNIDO EIP and Global Alliance of Special Economic Zones (GASEZ) UN SDG Model Zone certification. Direct SDG alignment across SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Industrial symbiosis is highly suitable for MENA industrial parks and dominant sectors, with proven and ready-to-scale benchmarks

FEV's global benchmarking of eleven industrial symbiosis ecosystems, including Kalundborg (Denmark), Ulsan (South Korea), Port of Rotterdam (Netherlands), and Kwinana (Australia), confirms that the sectors dominating MENA industrial parks (oil refining, petrochemicals, cement, steelmaking, and logistics) are precisely those where industrial symbiosis delivers the highest returns. The Sohar Industrial Port Area in Oman, KEZAD in Abu Dhabi, and Tanger Med in Morocco already display several industrial symbiosis-enabling characteristics. A structured FEV industrial symbiosis assessment of these zones could unlock significant commercial, ESG, and investment value within a 2–3-year implementation window.

Recommendations

01 Policy **Mandate industrial symbiosis screening**	Require industrial symbiosis compatibility assessment in all new SEZ master plans and environment and social impact assessment processes. Introduce incentives linked to industrial symbiosis such as reduced land lease rates, fast-track licensing, and green infrastructure grants to reward early adopters. Embed UNIDO EIP standards into SEZ enabling legislation as a prerequisite for GASEZ UN SDG Model Zone accreditation.
02 Finance **Deploy green finance**	Structure industrial symbiosis enabling infrastructure (district heating, shared wastewater, CO_2 pipelines, microgrids) as green bond issuances backed by quantifiable CO_2 reduction and resource efficiency metrics. Engage financiers, banks and development banks (e.g. EBRD and World Bank/IFC) as co-investors in PPP frameworks that appropriately distribute industrial symbiosis infrastructure risk between public authorities and private operators.
03 Action **Commission FEV industrial symbiosis pilots**	Identify 2–3 MENA zones with high industrial symbiosis potential for rapid feasibility assessment using FEV's proprietary simulation model. FEV and NurZen provide end-to-end industrial symbiosis advisory which covers feasibility and techno-economic modelling, EIP framework alignment, PPP structuring, digital platform design, and implementation support. Pilot results can provide investment grade projects within 12 months.

To explore how FEV's industrial symbiosis model can be applied to your zone, contact: energy@fev.com | https://www.fev.energy/

Chapter 1 Introduction

Special economic zones (SEZs) and industrial parks across the Middle East and North Africa (MENA) region are at a pivotal inflection point. Once valued primarily as low-cost manufacturing platforms, these zones are now attractive to international investors, national governments, and development finance institutions through the lens of environmental, social, and governance (ESG) performance, decarbonisation alignment, and contribution to the UN Sustainable Development Goals (SDGs).

This white paper sets out the strategic and operational case for adopting industrial symbiosis and circular economy principles within SEZs and industrial parks, with a particular focus on MENA jurisdictions. The paper is based on key essential themes as shown below, which are highly critical to modern and successful SEZs and industrial parks. It draws on FEV's global benchmarking research, proprietary industrial symbiosis simulation frameworks, and NurZen's SEZ expertise, investor attraction services, and knowledge of United Nations Industrial Development Organization (UNIDO) EIP standards to provide a practical roadmap for SEZ policymakers, zone developers, and their advisors.

Key theme	Insight	Recommendation
Industrial symbiosis	Proven CO_2 reduction & OPEX savings at scale	Mandate industrial symbiosis screening for all new SEZ master plans
MENA ESG momentum	ESG-aligned FDI is now a prerequisite, not optional	Embed EIP standards in SEZ licensing & incentive frameworks
Market resilience	Going beyond sustainability by adopting diversification strategies for price shocks	Diversify feedstock inputs and market access for managing shocks
FEV technology model	Full industrial symbiosis deployment: ~€2.4bn CAPEX + infrastructure investments, ~3.2 Mt CO_2/yr reduction	Pilot symbiosis projects via PPP in MENA priority zones

Table 1.1: Key themes, insights and recommendations of this whitepaper

Purpose and audience

This white paper is directed at two principal audiences. First, SEZ policymakers including government ministries, zone authorities, and regulatory bodies who are seeking evidence-based frameworks for embedding decarbonisation and circularity into zone legislation, master plans, and incentive structures. Second, SEZ developers and operators who require a credible, investable model for integrating industrial symbiosis technologies and business models into their zones. This not only builds the zone profile to attract green investment but, in most cases, provides a revenue stream to be more competitive.

Scope and structure

The paper is structured across six chapters:

Chapter 2: sets out the strategic rationale for industrial symbiosis in SEZs, covering the evolution of ESG-aligned FDI and MENA-specific investment dynamics.

Chapter 3: describes the UNIDO EIP framework that underpins the recommended approach.

Chapter 4: presents benchmark insights from leading global industrial symbiosis ecosystems and MENA SEZ sustainability leaders.

Chapter 5: introduces FEV's proprietary industrial symbiosis simulation model, technology enablers, and techno-economic results.

Chapter 6: closes with policy and investment recommendations for MENA decision-makers.

The analysis confirms that industrial symbiosis, when properly designed and supported by enabling technologies, can reduce CO_2 emissions by millions of tonnes per year, deliver millions in cost savings, and position SEZs as globally competitive, ESG-compliant investment destinations.

Chapter 2 Why industrial symbiosis for SEZs and industrial parks?

Industrial symbiosis (IS) describes the collaborative exchange of materials, energy, water, and by-products between co-located industries, such that the waste or surplus of one facility becomes the feedstock or input of another. While the concept is relatively well established in Europe and East Asia, it remains significantly under-exploited in the MENA region where the combination of rapid industrial growth, decarbonisation commitments, and escalating investor ESG demands creates an urgent and compelling opportunity. Lastly, industrial symbiosis is also a key concept to make zones more resilient to climate change, geopolitics and economic shocks by allowing industries more flexibility in sourcing inputs and accessing markets.

1. The transition from cost hubs to sustainability hubs

SEZs and industrial parks are evolving from cost-driven clusters to innovative and sustainability hubs. UNIDO's EIP framework and United Nations Conference on Trade and Development's (UNCTAD) SDG Model Zone[1] initiative explicitly identify SEZs as policy accelerators for SDG-linked investment, not simply tax-efficient industrial parks. This transition is not symbolic and is increasingly commercially driven, with substantial economic benefits in terms of jobs, skills, and social benefits.

Traditional SEZ model	ESG aligned SEZ model (2025+)
Low-cost manufacturing base	Energy efficient, sector specific clusters
Generic fiscal incentives	ESG conditional incentives & fast track licensing
Weak environmental oversight	Mandatory resource efficiency & industrial symbiosis standards
Isolated zones	Integrated urban, supply chain, logistics & circular ecosystems
Race to the bottom on cost	Differentiation through sustainability performance

Table 2.1: Comparison of traditional and ESG-aligned SEZ model

2. The ESG and SDG imperative in MENA

Over the past five to seven years, ESG in MENA has undergone a structural shift. What began as sustainability-led initiatives and voluntary reporting is increasingly moving into the domains of risk management, governance, and compliance. This shift is particularly acute for OECD investors, sovereign wealth funds, and development finance institutions (DFIs), all of which now apply rigorous ESG screening at the country, zone, and project level. Empirical evidence demonstrates that strong sovereign ESG performance correlates positively with foreign direct investment (FDI) inflows across Gulf states, particularly where trade openness and governance reforms exist. Weak ESG performance is increasingly priced as regulatory, energy-transition, and social value risk. SEZs therefore operate as the primary ESG transmission mechanism between governments and foreign investors[2].

[1] SDG Model Zones | World Investment Forum
[2] MDPI, (2024)

UN SDG priorities in MENA

In MENA, investors apply SDGs differently than in Europe or North America[3]. Capital allocation tends to concentrate on:

- SDG 7 (Affordable and Clean Energy): renewable integration and energy access
- SDG 9 (Industry, Innovation and Infrastructure): industrial upgrading and industrial symbiosis infrastructure
- SDG 8 (Decent Work and Economic Growth): job creation, localisation, and skills
- SDG 11 (Sustainable Cities and Communities): integrated zone-urban ecosystems
- SDG 12 (Responsible Consumption and Production): circular material flows and waste reduction

Figure 2.1: UN Sustainable Development Goals | Source: UN

3. Industrial symbiosis as a strategic enabler

Industrial symbiosis directly addresses the three core dimensions of SEZ competitiveness: 1) economic performance through cost reduction and resource efficiency; 2) environmental performance through air quality, emissions, and waste reduction; and 3) social performance through quality employment and community benefit. Global examples from Kalundborg in Denmark to Ulsan in Korea and Sohar in Oman demonstrate that industrial symbiosis delivers measurable, bankable outcomes that satisfy investor, regulator, and community expectations simultaneously.

The business case is compelling, as shown by FEV's modelling of an industrial park with full industrial symbiosis deployment can reduce CO_2 emissions by approximately 3.2 million tonnes per year and generate annual cost savings in the range of €4 billion, with a payback period of 3 to 10 years.

[3] Hassen, T., El Bilali, H. (2022)

Chapter 3 UNIDO eco-industrial park (EIP) framework alignment

The UNIDO EIP framework provides the internationally recognised standard against which SEZ sustainability performance is benchmarked. An EIP is defined as "a dedicated area for industrial use at a suitable site that ensures sustainability through the integration of social, economic, and environmental quality aspects into its siting, planning, management and operations." [4]

1. Definition and scope

Eco-industrial parks represent the evolution of traditional industrial parks into managed areas that integrate a comprehensive set of sustainability dimensions:

- Resource efficiency and cleaner production
- Industrial symbiosis and circular material flows
- Climate change mitigation and adaptation
- Pollution prevention and control
- Social standards, community engagement, and occupational health
- Shared infrastructure for utilities, logistics, and services
- Protection and enhancement of ecosystem services

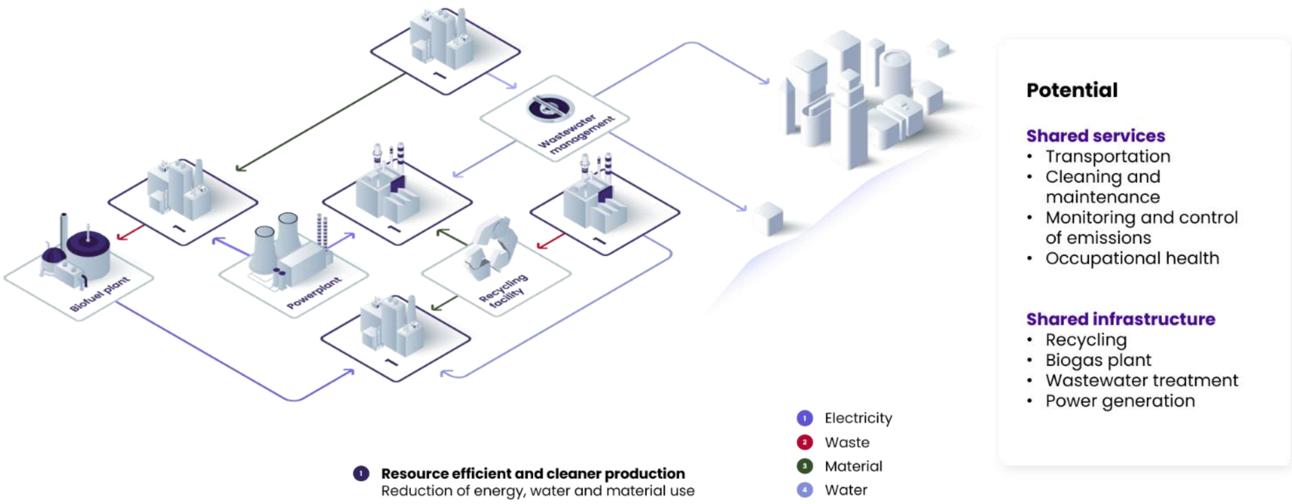


Figure 3.1: UNIDO eco-industrial park framework overview | Source: UNIDO (2017) [Global Eco-Industrial Park Programme – Transforming Industrial Parks for a Sustainable Tomorrow]

2. Evolution of the EIP concept

Global trends in SEZ development show a clear progression across three generations. Zones 1.0 are efficiency-driven, cross-industry platforms competing primarily on cost. Zones 2.0 introduce environmental and social governance, attracting higher-value investment. Zones 3.0 – the EIP model – are fully integrated circular economy ecosystems, incorporating net-zero energy, industrial symbiosis, digital management platforms, and aligned with SDG investment frameworks. For MENA economies, the transition to Zones 2.0 and 3.0 represents the primary route to upgrading industrial production from resource-based to knowledge and services-oriented value creation.

[4] UNIDO, 2017

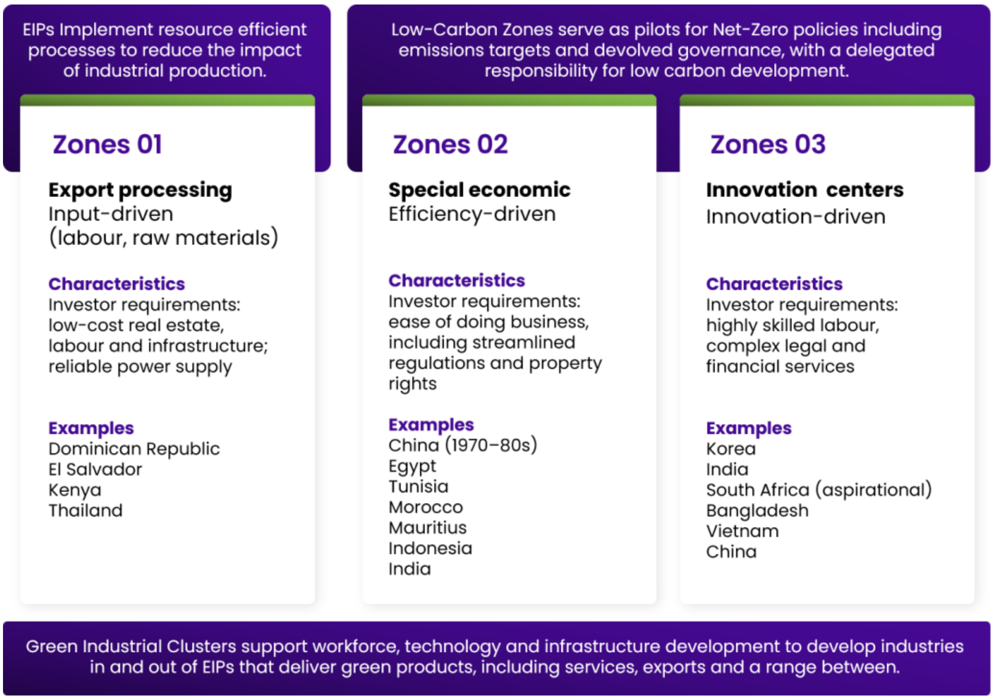


Figure 3.2: Evolution of economic zone development pathways | Source: NurZen analysis

3. The four UNIDO EIP dimensions

The UNIDO framework identifies four core performance dimensions: environmental, economic, social, and park management. Environmental performance covers resource efficiency, industrial symbiosis synergies, and low/zero-carbon energy development. Economic performance encompasses FDI attraction, employment generation, and investment competitiveness. FEV's industrial symbiosis model directly addresses both these dimensions.

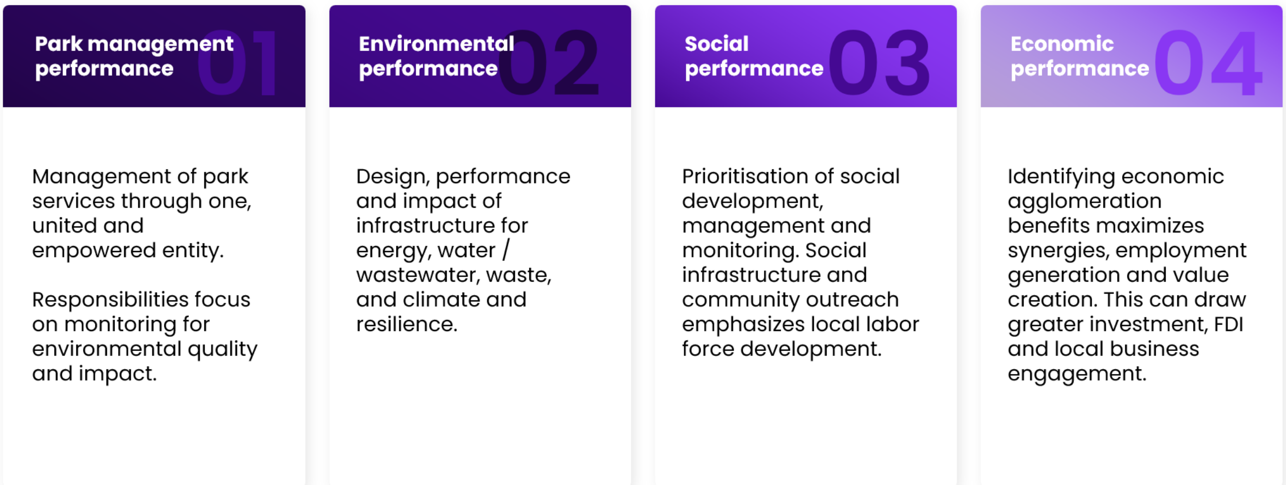


Figure 3.3: UNIDO EIP — Four core performance dimensions (UNIDO, 2017)

4. UN Sustainable Development Goals (SDG) alignment

UNIDO's EIP framework maps directly to the UN SDGs, reinforcing EIP certification as a signal to ESG-aligned investors. This white paper specifically focuses on SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), the SDGs most directly addressed by industrial symbiosis.

Chapter 4 Benchmark insights from SEZ sustainability performance

This chapter synthesises two complementary evidence bases: 1) FEV's global analysis of eleven industrial symbiosis ecosystems and 2) the MENA SEZ sustainability landscape drawing on GASEZ, UNCTAD, and primary market research. Together, they establish the global best practice baseline against which MENA zones should be assessed and to which FEV's proposed industrial symbiosis model is calibrated.

1. Global industrial symbiosis benchmarks

FEV analysed eleven leading industrial parks and symbiosis ecosystems globally, identifying more than 150 participating companies and cataloguing the industry compositions, resource exchange patterns, and enabling technology deployments that underpin their success. The table below summarises the key industrial parks and their industrial symbiosis characteristics.

Industrial symbiosis ecosystem	Country	Core industries	Key symbiosis	Key metrics / outcomes	MENA relevance
Kalundborg	Denmark	Oil refinery, combined heat and power (CHP), pharma, cement, recycling	Waste heat, steam, fly ash, sludge, CO_2 exchange	~275,000 t CO_2/yr saved; water savings >3M m³/yr	High: refinery + utilities model replicable in Gulf
Kwinana	Australia	Refinery, cement, energy, chemicals, recycling	Oxygen, hydrogen, steam, CO_2, cooling water	A$100M+/yr in economic benefits; 20+ industrial symbiosis linkages	High: heavy industrial park analogue for Sohar, Jubail
Ulsan	South Korea	Petrochemicals, steel, shipbuilding, green H_2	By-product gases, waste heat, green hydrogen hub	15% industrial CO_2 reduction; national green H_2 hub	High: green hydrogen and petrochemical synergies
Port of Rotterdam	Netherlands	Refinery, chemicals, port logistics, renewables	CO_2 capture, H_2 pipelines, steam, industrial gases	Pioneer of carbon capture and H_2 infrastructure	High: port-industrial zone archetype for MENA
Kawasaki Eco-town	Japan	Steel, cement, recycling, chemicals, plastics	Waste material loops, slag reuse, heat recovery	7 eco-town zones, >80% waste diversion from landfill	Medium: waste-to-resource model for circular SEZs
Styria (Austria)	Austria	Pulp & paper, packaging, chemicals, energy	Fibre, steam, chemicals, energy exchange network	Cluster of 30+ firms; multi-sector IS	Medium: Small and medium-sized enterprise (SME)-led industrial symbiosis model for diversified zones

Table 4.1: Global industrial symbiosis ecosystem benchmarks | Source: FEV analysis (2025)

Cross-cutting findings

Across the eleven parks analysed by FEV, several structural patterns consistently emerge. Chemical industry and construction materials sectors (cement, steel) are present in virtually all successful industrial symbiosis ecosystems. An energy or fuel production facility is present in every case, providing the waste heat, steam, or by-product gases that anchor the symbiosis network. Recycling facilities and wastewater management plants are the most common utility-side participants, acting as resource recovery hubs. District heating networks are present in approximately half of cases, converting waste heat into a commercial product. The Ulsan case study below demonstrates the positive impact of upgrading to an EIP, especially economic resilience of less imports, local jobs for SMEs, and engagement with the local community.

Overview:

Ulsan / Mipo Onsan Industrial Complex

Ulsan Mipo and Onsan is part of South Korea's eco-industrial park initiative, which seeks to transform traditional industrial complexes into sustainable EIPs. Firms in Ulsan Mipo and Onsan have invested some $520 million in energy efficiency, industrial symbiosis, waste management, and other eco-friendly improvements. To date, the investment has yielded $554 million in savings, while firms in the EIP generated $91.5 billion in revenues. Spurred by government investment of $14.8 million, companies in the park reduced their CO_2 emissions in 2015–2016 by 665,712 tons, reused 79,357 tons of water, and saved 279,761 tons of oil equivalent in energy use. These changes have enhanced relations with local communities by improving the negative image of industrial complexes as polluters.

Key distinguishing factors

- Koentec Ltd. – Industrial waste treatment and disposal company with incinerator capacity of 300 ton/day and landfill;
- SK Chemicals Corp. – Provides recycled water after removing chemicals;
- Ulsan Metropolitan City – operates the Ulsan Municipal Wastewater Treatment Plants (350,000 m³/day);
- Some unique technologies like plastic separation, solvent recycling and recovery, recovery of byproducts, wastewater treatment and use are also used.

Key industries

- Vehicle and ship building
- Oil refineries
- Non-ferrous metals
- Fertilizers
- Chemical symbiosis

No. of companies	1,000+
No. of employees	100,000+
Revenue generated	$91.5 Bn+

Positive impacts by upgrading from IP to EIP

- Reduction CO_2 and other toxic gases through considerable savings in energy and material use;
- Creation of new business opportunities and employment opportunities from by products and waste recycling that generated additional incomes for participating companies;
- Sizable new investment in industrial facilities and infrastructure and the creation of new jobs;
- Improvement of air and water quality, and thus improved relationships with local communities Improvement in the negative image of industrial complexes; and
- Less imports and better utilisation of existing resources for energy requirements

Table 4.2: SEZ benchmark sustainability performance overview | Source: NurZen analysis

2. Priority technology enablers for MENA

FEV's analysis of eleven industrial symbiosis parks, combined with MENA-specific conditions, identifies four technology categories with the highest deployment priority. Electricity-based technologies, particularly solar photovoltaic (PV) and electrolysis for green H_2. Both are highly suitable given MENA's solar resource. Heat-based technologies, including Organic Rankine Cycle and thermal storage, leverage the abundant industrial waste heat available in refinery and cement clusters. Anaerobic digestion and point source CO_2 capture are critical for circular economy and decarbonisation objectives, respectively.

3. MENA SEZ sustainability leaders

Within the MENA region, several SEZs have already demonstrated meaningful progress in ESG-aligned investment attraction and sustainability practices, establishing the benchmark for the region. These zones provide the most direct comparators for new and developing SEZs seeking to adopt industrial symbiosis and EIP frameworks. The table below summarises some of the latest sustainability and resilience practices SEZs are currently adopting.

SEZ / zone	Country	ESG / SDG highlights	Key sustainability practices	GASEZ SDG zone
Dubai Silicon Oasis	UAE	GRI aligned disclosure; ESG screening for cleantech, AI & circular economy FDI; SDG 9, 7, 11	Mandated energy efficiency; preferential licences for renewables & circular economy (CE) firms	Yes: GASEZ SDG Model Zone
Abu Dhabi SEZs (KEZAD)	UAE	Large scale solar PV; clean hydrogen pilot; ISSB-aligned reporting emerging	Integrated renewable energy; circular economy in logistics	Recognised exemplar
NEOM / economic cities	Saudi Arabia	Vision 2030 embedded ESG; green H_2 megaproject (NEOM); SDG 8, 9, 12	Renewable energy incentives; water-intensity licensing; SDG-aligned workforce localisation	In progress
Tanger Med zones	Morocco	Africa-MENA's most mature ESG logistics and industrial SEZ; EU carbon border adjustment method (CBAM) proximity advantage	Renewable energy in port & zone ops; strong EU supply chain labour compliance	Yes: GASEZ SDG Model Zone
Qatar free zones (QFZA)	Qatar	Green building mandates; QNV 2030 alignment; UN-backed SDG platform for advanced manufacturing	Social compliance in zone regulation; green procurement standards	Yes: GASEZ SDG Model Zone

Table 4.3: MENA SEZ sustainability benchmark | Source: NurZen / GASEZ (2024) / UNCTAD

Notes:

The Global Reporting Initiative (GRI) is an independent, international non-profit organization that develops globally recognised standards for sustainability reporting, helping organisations measure, understand, and communicate their ESG impacts effectively.

The Carbon Border Adjustment Mechanism (CBAM) is an EU regulation that imposes a carbon price on imported goods based on their embedded emissions to prevent carbon leakage and align imports with EU carbon pricing.

The Qatar National Vision 2030 (QNV 2030) is the country's long-term development framework, launched in 2008, that guides Qatar's economic, social, human, and environmental progress up to the year 2030.

The GASEZ SDG Model Zone initiative aims to enhance the contribution of special economic zones to sustainable development. The initiative was launched on 18 October 2023 during the UNCTAD World Investment Forum in Abu Dhabi. The founding members of GASEZ have identified 50 SEZs from across the world as nominees for SDG Model Zones.

4. Key performance indicators (KPI) benchmark dashboard

The following KPI framework consolidates the performance metrics tracked across the benchmarked industrial symbiosis ecosystems and MENA SEZs. This dashboard is intended as a living reference tool for SEZ operators and policymakers to assess their own zones against best-in-class performance. This dashboard helps in understanding how zones can become competitive, resilient, and innovative. It can be used for monitoring as well as gap assessments for future investment decisions, including diversification strategies.

KPI category	KPI metric	Global leader benchmark	MENA average (est.)	MENA target (2030)
Environmental	CO_2 reduction (kt/yr)	275 kt (Kalundborg)	10–30 kt	>80 kt
Environmental	Renewable energy share (%)	40–80% (Ulsan, Kwinana)	5–20%	>40%
Environmental	Waste diversion from landfill (%)	>80% (Kawasaki)	20–40%	>60%
Resource efficiency	Water recycling rate (%)	>70% (Kalundborg)	15–30%	>50%
Resource efficiency	Waste heat recovery rate (%)	Capturing 40–60% of rejected heat and savings of 15 - 25% in thermal costs compared to conventional boilers.	NA	NA
Economic	OPEX savings (% of baseline)	10–25%	<5%	>12%
Economic	Industrial symbiosis payback period (years)	3–10 years	N/A	<10 years
Governance	ESG disclosure standard	GRI / ISSB (most leaders)	Emerging	GRI-aligned

Table 4.4: SEZ industrial symbiosis KPI benchmark dashboard | Source: FEV and NurZen analysis

Notes:

The International Sustainability Standards Board (ISSB) standards, IFRS S1 and S2, provide a global baseline for sustainability and climate-related disclosures to support investor decision-making and comparability across markets.

MENA average figures are FEV and NurZen estimates based on GASEZ (2024), IRENA and UNCTAD (2023) data, internal modelling and analysis, zone assessments and previous studies. The global benchmarks are drawn from FEV industrial symbiosis analysis and published zone-specific industrial symbiosis ecosystem reporting.

GRI (Global Reporting Initiative) and ISSB are the de facto global standards.

Chapter 5 Proposed industrial symbiosis model for SEZs

FEV has developed a simulation framework specifically designed to evaluate whether industries within an SEZ or industrial park can mutually benefit from industrial symbiosis, and to assess whether such synergies can facilitate measurable progress towards sustainability and decarbonisation objectives. The proposed model is conceived as a digital twin of an industrial park, providing a dynamic environment for simulating and optimising resource flows, emissions, costs, and technology integration.

1. Model architecture

Unlike static planning tools, FEV's industrial symbiosis model is both descriptive and predictive, enabling stakeholders to evaluate operational scenarios and long-term sustainability strategies with high accuracy. The model is user-driven as the operator defines the industries to be included in the park, specifying their approximate size and production capacity. Industries can range from large-scale, carbon-intensive sectors such as oil refining, cement, and steelmaking to mid-sized industries like food processing and paper manufacturing, which have moderate resource demands but significant potential for heat recovery and by-product valorisation.

Once the industrial portfolio is configured, the model applies advanced optimisation algorithms to determine the optimal sizing and deployment of enabling technologies. The objective is to maximise industrial symbiosis benefits across three critical dimensions: CO_2 emission reduction; financial performance (return on investment (ROI), payback period, OPEX savings); and resource efficiency (energy, water, and material streams).

2. Industry cluster typology

The model organises participating industries into four strategic clusters to identify the optimal industrial symbiosis potential (Table 5.1).

Cluster	Example industries	Industrial symbiosis potential
Heavy & energy-intensive	Oil refineries, cement, steelmaking, synthetic fuels	Large-scale heat recovery, carbon capture, shared utilities provide the highest CO_2 reduction potential
Chemical & process	Methanol, agrochemicals, industrial gases	Feedstock exchange, green H_2 integration, CO_2 utilisation
Utilities & circular services	Recycling, wastewater treatment, district heating	Resource recovery hubs; close material and water loops
Mid-sized resource-moderate	Paper, food processing, packaging	Heat integration, by-product valorisation, biogas from organic waste

Table 5.1: FEV industrial symbiosis model — Industry cluster typology

3. Technology enablers

To unlock synergies among industry clusters, the model integrates ten enabling technologies in four functional categories. Electricity-based technologies (PV, electrolyser, heat pumps, BESS) provide renewable power and green hydrogen. Heat-based technologies (ORC, thermal storage) recover and redistribute waste heat. Chemical-based technologies (combustion heaters, gasification, anaerobic digestion) convert waste streams to energy. Carbon capture technologies enable point-source CO_2 recovery at cement, steel and refinery facilities.

4. Techno-economic analysis

By integrating CO_2 reduction, financial and resource efficiency parameters, the model delivers a techno-economic blueprint for industrial symbiosis that is scalable, adaptable, and aligned with decarbonisation targets. It empowers decision makers to identify high-impact synergies, prioritise investments, and mitigate risks, all within a virtual environment that mirrors the complexity of real industrial ecosystems. FEV's techno-economic analysis models each technology with its current performance characteristics and cost structure, while allowing for dynamic updates of CAPEX, OPEX, and efficiency factors as technologies mature. This ensures the model remains a living decision-support tool rather than a one-time feasibility study. As electrolyser efficiency improves or carbon capture costs decline, the model recalculates financial KPIs instantly.

Main streams and utilities driving symbiosis benefits

The greatest value in industrial symbiosis arises from optimising energy, material, and utility streams that are abundant and transferable across multiple sectors. High-grade waste heat from energy-intensive industries such as cement, steelmaking, and oil refining can be recovered and redistributed through district heating networks, reducing fuel consumption for adjacent facilities and lowering overall emissions. Similarly, low-grade heat from processes like food manufacturing and paper production can be upgraded via heat pumps for secondary uses, creating a cascading energy system that minimises thermal losses.

On the material side, CO_2 streams from heavy emitters become feedstock for chemical processes such as methanol synthesis or synthetic fuel production, while organic waste streams from food and paper industries are converted into biogas through anaerobic digestion, providing renewable energy and reducing landfill dependency. Shared utilities, including water treatment and recycling systems, further enhance resource efficiency by closing loops for water and raw materials. When integrated with energy storage solutions, these synergies stabilise supply and demand, ensuring resilience against fluctuations in renewable generation and industrial load. Collectively, these interconnected streams form the backbone of a scalable, circular ecosystem that maximises economic and environmental benefits for industrial parks.

5. Results and performance outcomes

The analysis demonstrates the progressive benefits of industrial symbiosis across three scenarios:

1. **Baseline scenario (no symbiosis):** In this configuration, industries operate independently, with no exchange of energy or material streams. This results in high operational costs, inefficient resource utilisation, and elevated CO_2 emissions. The absence of shared utilities or heat recovery leads to significant energy losses and missed opportunities for cost optimisation.

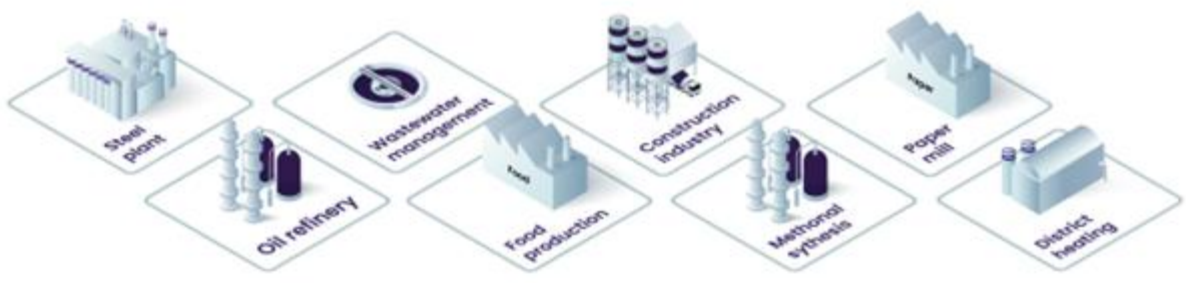


Figure 5.1: Baseline scenario – illustrative example

2. **Partial symbiosis (industry-to-industry integration):** Introducing symbiosis between industries such as heat cascading, shared water treatment, and material reuse delivers measurable improvements. Resource efficiency increases, and operational costs begin to decline as waste heat and by-products are valued within the park. While this scenario reduces emissions compared to the baseline, the impact remains moderate due to limited technology integration.

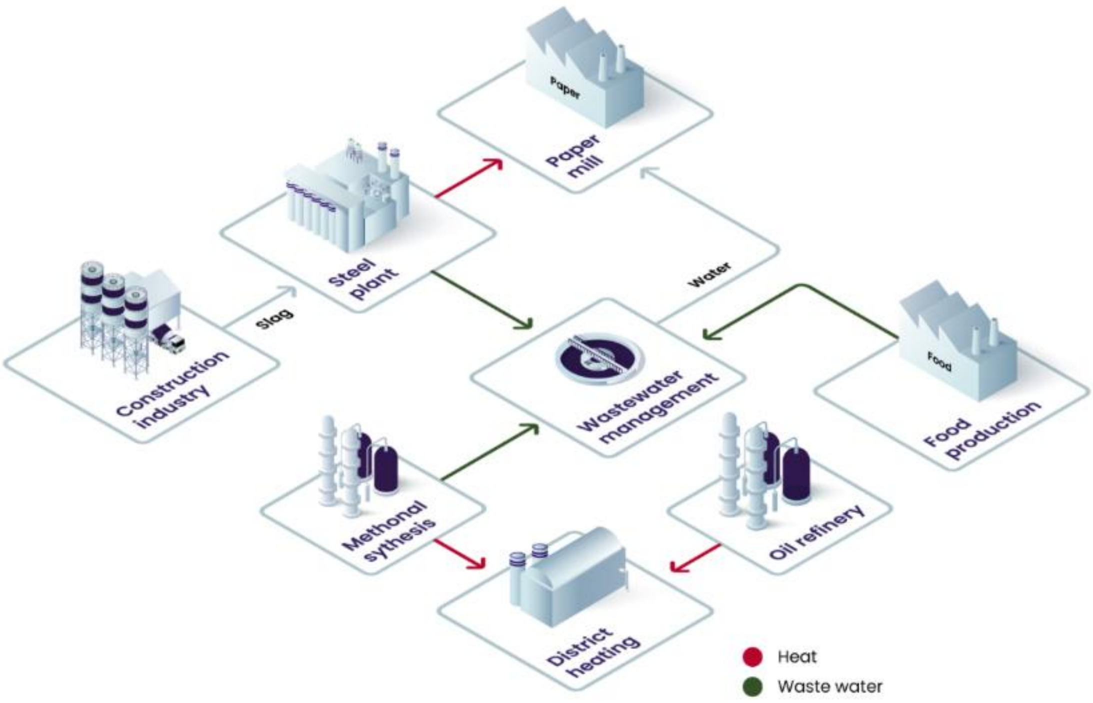
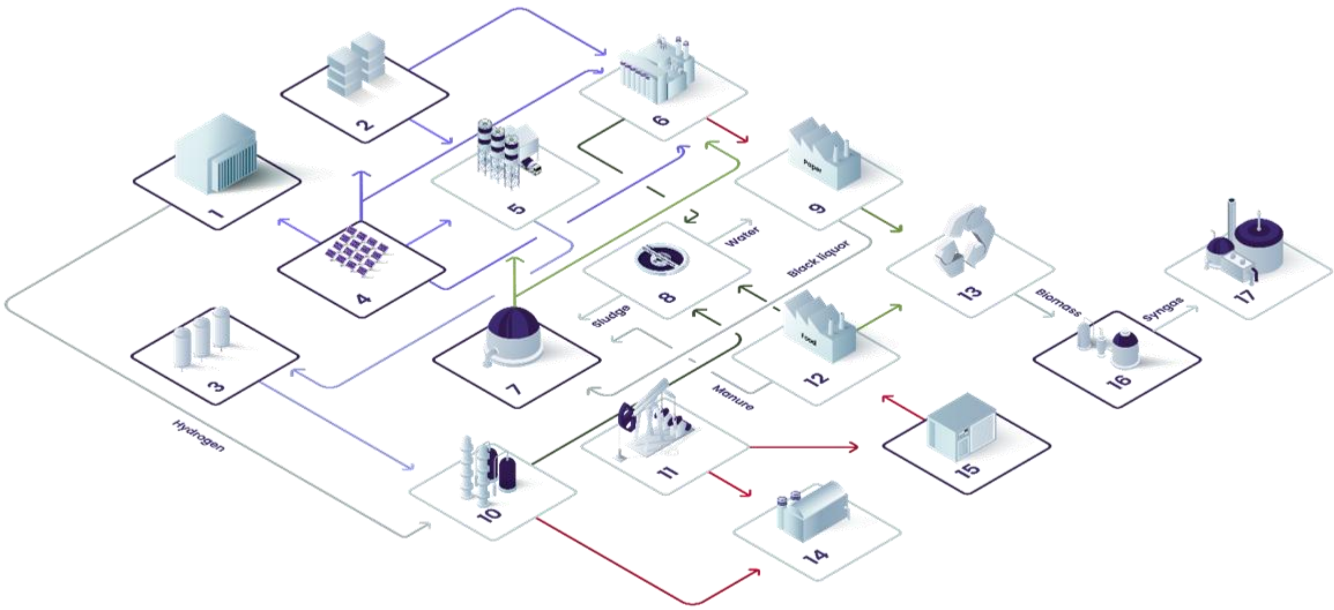


Figure 5.2: Partial symbiosis scenario – illustrative example

3. **Full symbiosis (industry and technology integration):** The most substantial benefits occur under full symbiosis, where advanced technologies complement inter-industry exchanges. This includes renewable energy systems, biogas production from organic waste, and carbon capture solutions installed at major emission points.



1. Electrolyzer
2. Battery storage
3. Point source carbon capture
4. PV production plant
5. Construction industry
6. Steel plant
7. Anearobic digestion
8. Wastewater management
9. Paper mill
10. Methonal sythesis
11. Oil refinery
12. Food production
13. Recycling facility
14. District heating
15. Heat pump
16. Gasification
17. Biogas

1. Electricity
2. Heat
3. Waste
4. Waste water
5. Biogas
6. CO_2

Figure 5.3: Full symbiosis scenario – illustrative example

Performance metric	Baseline (no IS)	Partial IS	Full industrial symbiosis + technology integration
CO_2 reduction potential (t/yr)	0	~500,000 - 800,000	Up to 3,200,000 (3.2 Mt/yr)
OPEX saving potential (€/yr)	—	Moderate	Up to €4 billion
Capital investment into technologies (CAPEX Tech.)	—	Incremental	~€2.4 billion
Payback period	—	Variable	3 to 10 years
Waste heat recovery	Low	Medium	High (multi-industry cascading)
Resource efficiency	Low	Medium	High (closed loops, biogas, H_2)

Table 5.2: Industrial symbiosis model performance outcomes by scenario | Source: FEV (2025–26)

Industrial symbiosis can deliver substantial emissions reductions and OPEX savings, often resulting in attractive payback periods for the CAPEX invested in enabling technologies. Beyond technology-specific investments, additional costs associated with establishing the symbiotic ecosystem must be assessed on a case-by-case basis. These may include, for example, the construction of heat pipes, shared utilities, or local microgrids. Such costs are highly site-specific and are primarily influenced by factors such as the distance between participating facilities, land availability and pricing, and local construction conditions, including labour costs and ground characteristics. A detailed definition of the industrial symbiosis configuration and a project-specific cost assessment therefore constitute a critical next step toward implementation and realisation.

Sensitivity analyses confirm the robustness of these results even under significant fluctuations in electricity prices (±20%) and gas prices (±30%), reinforcing the financial viability and resilience of the proposed approach. These findings underscore the strategic value of combining industrial cooperation with enabling technologies to achieve both economic and environmental objectives.

Scalability and adaptability: The model is designed to be flexible, scalable, and expandable within defined size thresholds, ensuring that most existing industrial parks can be simulated in the framework to assess the symbiosis potential. By clustering industries and technologies, the system can be tailored to local resource availability, regulatory constraints, and economic priorities. This modular approach allows incremental deployment, starting with high-impact clusters and expanding as infrastructure and stakeholder engagement mature.

6. Implementation roadmap

Achieving full industrial symbiosis requires significant upfront investment, making PPPs crucial for success. The recommended implementation roadmap consists of four phases as shown in the table below.

Phase	Timeline	Activities	Milestones
1: Foundation	Years 1–2	Feasibility studies; material and energy flow mapping; stakeholder engagement; PPP structuring	Industrial symbiosis potential assessment; anchor tenant agreements; PPP framework signed
2: Infrastructure	Years 3–4	Shared utilities development; pipeline and heat network installation; data monitoring platform deployment	Operational district heating; shared wastewater treatment; industrial symbiosis data hub live
3: Technology deployment	Years 5–7	Pilot symbiosis projects (waste heat recovery, CO_2-to-fuel, biogas); technology scale-up; ESG certification	Pilot industrial symbiosis projects operational; renewable energy targets met; EIP/GASEZ certification achieved
4: Optimisation	Year 8+	Continuous improvement; digital twin operation; performance monitoring; expansion to additional industries	Full industrial symbiosis realised; KPI dashboard live; industrial symbiosis model exported to other zones

Table 5.3: Industrial symbiosis implementation roadmap

Chapter 6 Policy and investment recommendations

Industrial symbiosis transforms SEZs and industrial parks into eco-industrial ecosystems, delivering triple-bottom-line benefits and positioning them as globally competitive sustainability leaders. The following recommendations are directed at three principal audiences: SEZ policymakers and regulators; zone developers and operators; and the investment and finance community active in the MENA region.

1. Policy recommendations for SEZ authorities

- Integrate EIP principles into SEZ legislation and master plans. Embed UNIDO's four EIP performance dimensions into SEZ enabling acts, zoning regulations, and development frameworks. Make EIP certification a standard requirement for zones seeking GASEZ SDG Model Zone status.
- Develop IS-conditional incentive frameworks. Restructure fiscal and non-fiscal incentives to reward industrial symbiosis participation. Examples include reduced land lease rates for industrial symbiosis network participants, fast-track one-stop-shop (OSS) licensing for IS-enabled industries, and preferential access to green infrastructure grants.
- Mandate industrial symbiosis screening in zone planning approvals. Require all new industrial developments above a defined threshold to undergo industrial symbiosis compatibility assessment as part of the environmental and social impact assessment (ESIA) process.
- Create a MENA industrial symbiosis knowledge exchange platform. Establish a regional knowledge network, potentially anchored by GASEZ or a national SEZ authority, to share industrial symbiosis best practices, technology procurement guidance, and investor matchmaking services across MENA zones.

2. Finance and investment recommendations

- Deploy green bonds and blended finance for industrial symbiosis infrastructure. IS-enabling infrastructure such as district heating networks, shared wastewater treatment, CO_2 pipelines, and energy microgrids are natural candidates for green bond financing, given their quantifiable environmental impact and long-term revenue streams.
- Structure PPP frameworks that allocate industrial symbiosis infrastructure risk appropriately. PPPs enable risk-sharing between public authorities and private operators, accelerating infrastructure development for shared utilities and advanced technologies including carbon capture. MENA development finance institutions (IFC, EBRD, IsDB) should be engaged as co-investors.
- Align industrial symbiosis project returns with ESG capital markets. Industrial symbiosis projects should be structured to generate bankable ESG metrics based on verified CO_2 reduction, resource efficiency improvements, and SDG contribution reports, which satisfy institutional investor ESG due diligence requirements and unlock sustainability-linked financing.

3. Capacity building recommendations

- Develop industrial symbiosis training programmes for SEZ operators and tenants. Invest in structured capacity building to equip zone management teams and tenant industries with the technical knowledge required to identify, design, and operate industrial symbiosis synergies. Partner with FEV, UNIDO, and leading universities to deliver accredited programmes.
- Deploy digital industrial symbiosis management platforms. Invest in digital twin and resource exchange management systems that provide real-time visibility of material, energy, and water flows across the zone. These platforms are the operational backbone of a functioning industrial symbiosis network and the foundation for ESG reporting.
- Establish MENA industrial symbiosis pilot zones. Identify two to three MENA zones with favourable industry compositions for industrial symbiosis pilots. FEV's simulation model can provide a rapid feasibility assessment and techno-economic business case to support zone authority decision-making and investor engagement.

Our offer to MENA SEZ stakeholders

FEV energy + resources and NurZen provide end-to-end industrial symbiosis advisory services: from industrial symbiosis feasibility assessment and techno-economic modelling, through EIP framework alignment and PPP structuring, to digital platform design and industrial symbiosis implementation support. We invite MENA SEZ authorities and developers to engage with our team to explore how FEV's proven industrial symbiosis simulation model can be applied to your zone.

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