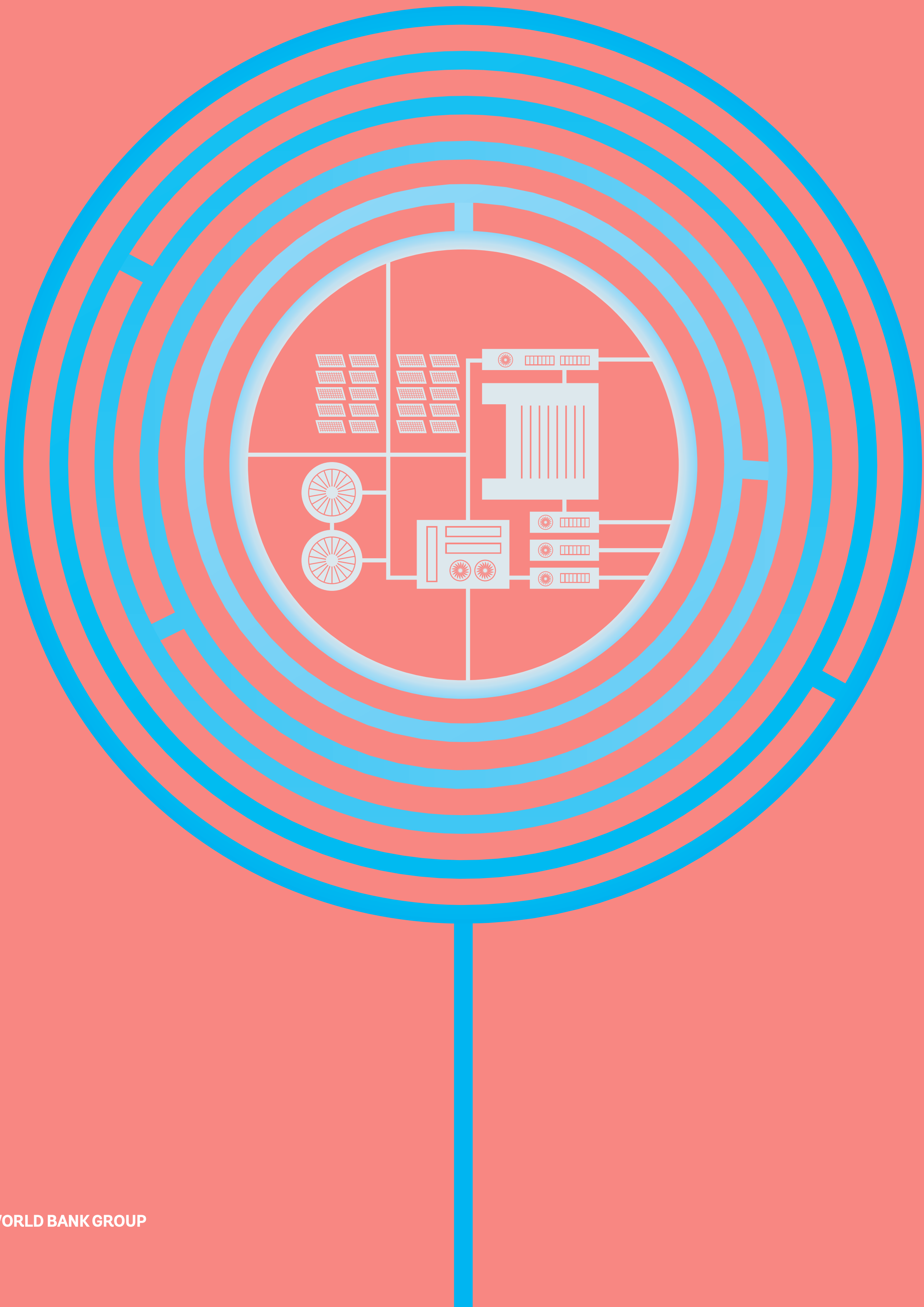
Circular Economy in Industrial Parks:

Technologies for Competitiveness



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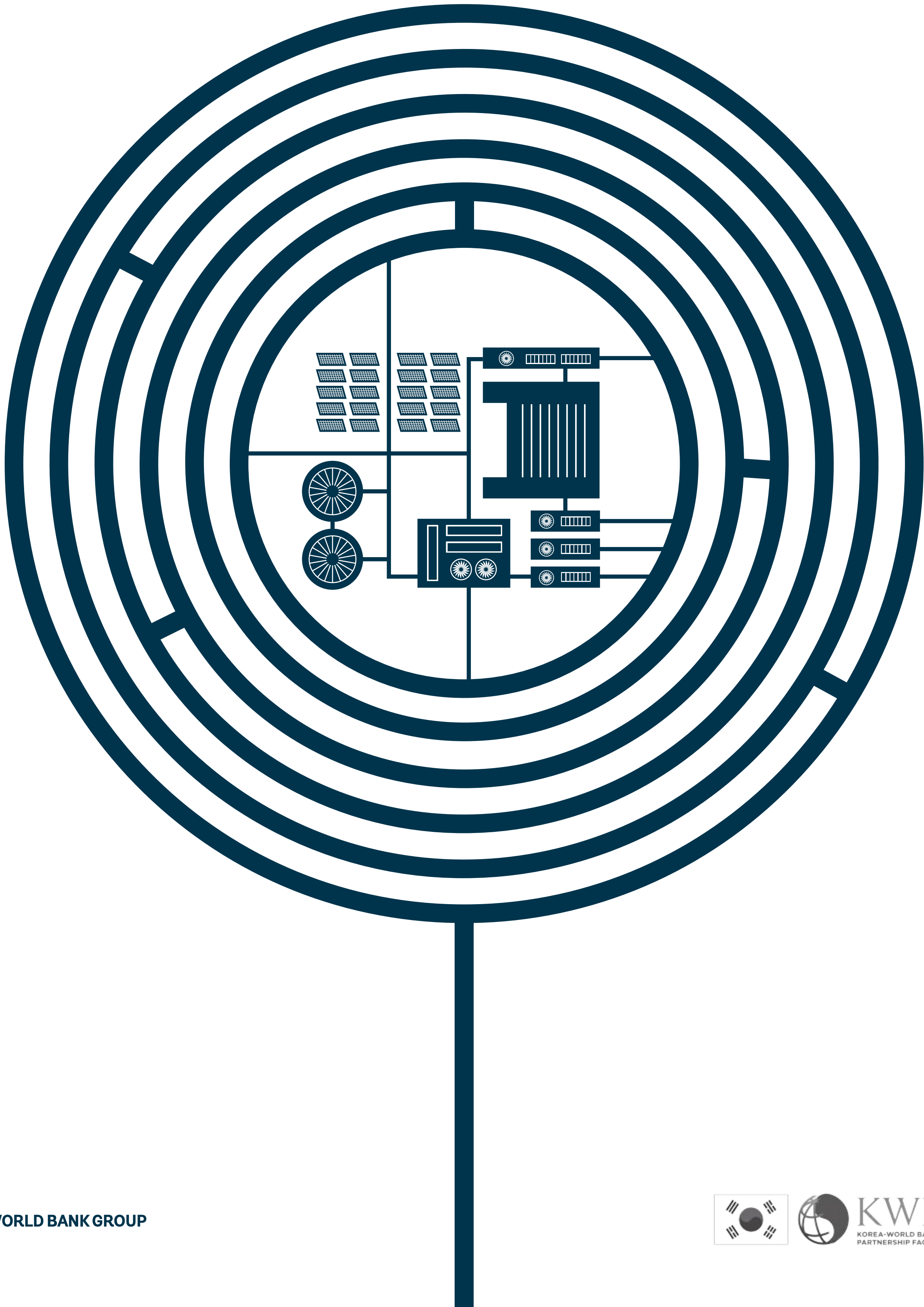

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Contents

Abbreviations

BOD	biological oxygen demand
CAGR	compound annual growth rate
CAPEX	capital expenditure
CE	circular economy
CETP	common effluent treatment plant
CHP	combined heat and power
COD	chemical oxygen demand
CSP	concentrating solar power
EAP	East Asia and Pacific
ECA	Europe and Central Asia
EIP	eco-industrial park
EMCC	Environmental Monitoring and Control Center
EMS	environmental management system
EnMS	energy management system
EPC	energy performance contract
ERC	Energy Regulatory Commission
ESS	energy storage system
ETP	effluent treatment plant
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
GIZ	German Agency for International Cooperation
H&S	health & safety
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IEC	integrated energy contract
IPP	independent power producer
IS	industrial symbiosis
M&E	monitoring & evaluation
MBR	membrane bioreactor
MED	multiple effect distillation
METI	Ministry of Economy, Trade and Industry
MF	micro filtration
MFC	microbial fuel cell
MOE	Ministry of Environment
MSF	multi-stage flash
NF	nano filtration
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OHS	occupational health and safety
OIZ	organized industrial zone
OPEX	operational expenditure
ORC	Organic Rankine Cycle
PM10	particulate matter up to 10 micrometers in size
PPD	public-private dialogue
PPP	public-private partnership
PUB	Public Utility Board
PV	photovoltaic
R&D	research and development
RECP	resource efficiency and cleaner production
RMB	renminbi
RO	reverse osmosis
ROI	return on investment
SBR	sequence batch reactor
SHC	solar heating cooling
SMEs	small and medium enterprises
SPP	small power producer
STP	sewage treatment plant
TDS	total dissolved solid
TSP	total suspended particulate
TSS	total suspended solid
UF	ultra-filtration
UNIDO	United Nations Industrial Development Organization
WWTP	wastewater treatment plant
ZLD	zero liquid discharge

Acknowledgments

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ES Executive summary

The circular economy is now at the forefront of the competitiveness agenda for various industrial sectors, industrial parks, and firms. This report intends to provide practical recommendations on how industrial parks can promote the circularity of resources and strengthen competitiveness through innovative technologies and business models, and what governments can do to support such initiatives. It also aims to assist policy makers in identifying enablers of and barriers to the adoption of the proposed technologies.

The key message of the report is that circular economy interventions are not just environmentally beneficial but also economically viable, and hence, can improve the competitiveness of industrial parks and tenant firms. Implementing circular economy principles in industrial parks requires honing in on innovative approaches. In particular, **eco-industrial parks (EIPs), as well as the technologies and business models adopted in EIPs, are important building blocks for scaling up the circular economy approach** and accelerating green, sustainable, and resilient industry growth. The report highlights EIP technologies, infrastructure investments, and business models in the following three areas: **energy** (primarily renewable energy technologies), **water** (water supply and wastewater treatment technologies), and **material and waste heat** (industrial symbiosis and other material recovery technologies).

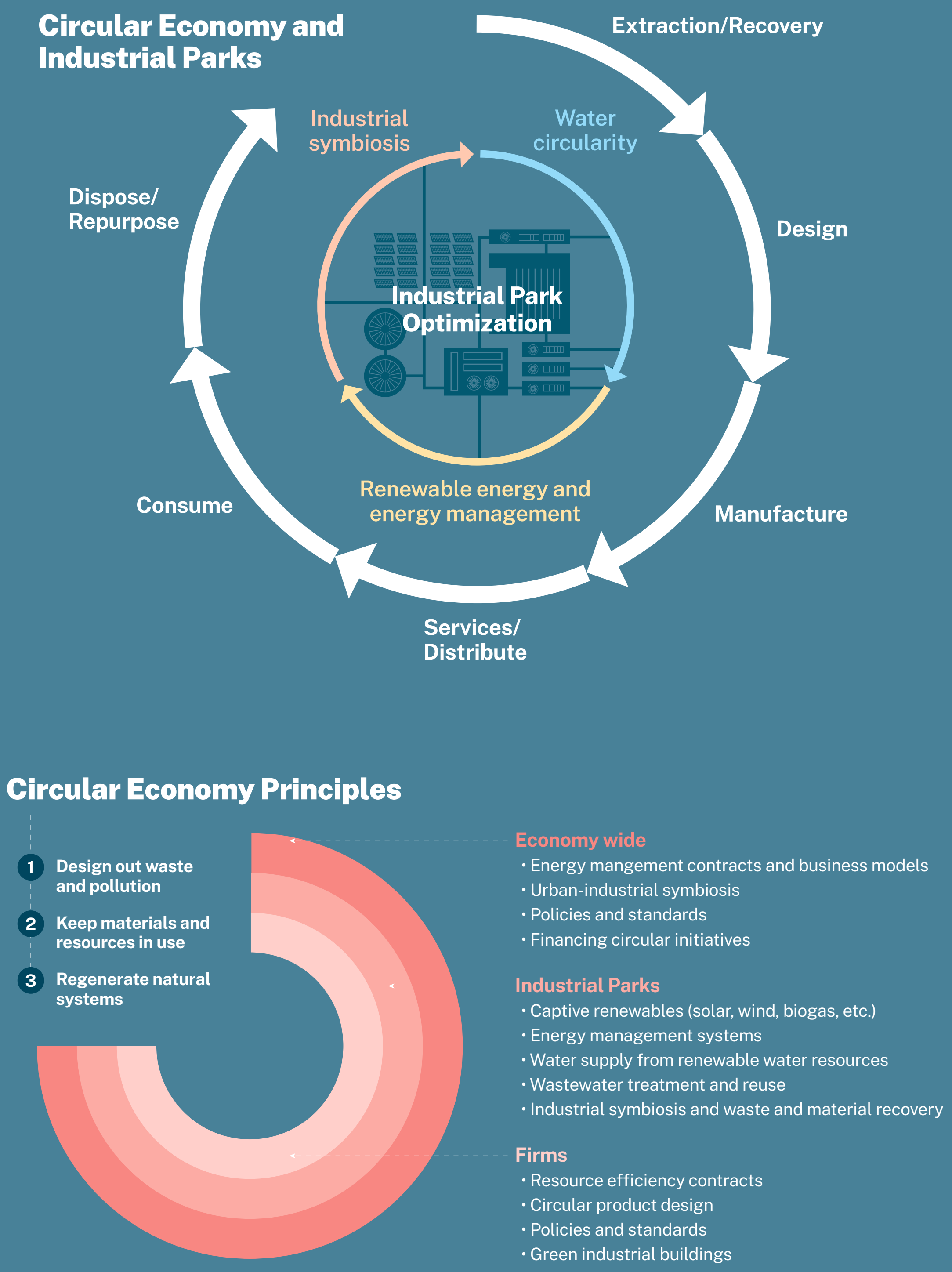
Industrial parks can adopt a combination of different strategies to foster the circular economy (figure ES.1):

» Promoting higher renewable energy generation and use, and achieving carbon neutrality

» Investing in common infrastructure and service provision to optimize the use of resources (e.g., steam networks, carbon dioxide (CO_2) recovery plants, cogeneration/ trigeneration using biomass and/or biogas)

» Keeping materials and resources in use at the park level by encouraging tenant firms to create a symbiotic network and enabling their waste and by-product exchange

FIGURE ES.1 • Circular economy principles applied in industrial parks



» Designing waste out by encouraging tenant firms to integrate circular designs and to use environmentally friendly technologies in their production facilities

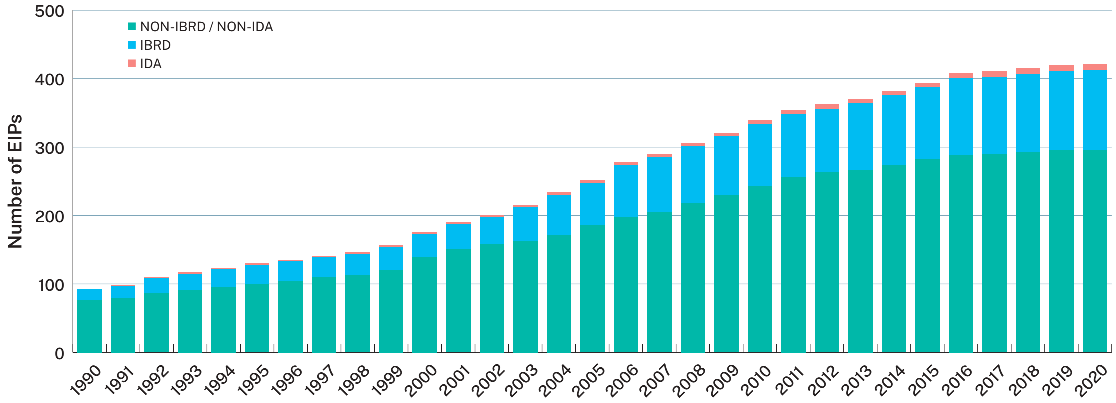
» Fostering the establishment of recycling enterprises and sorting facilities rendering services to tenant firms

» Rethinking business models for improved energy, water, and waste management at the park level

» Harnessing digital technologies to increase resource circularity and material exchange

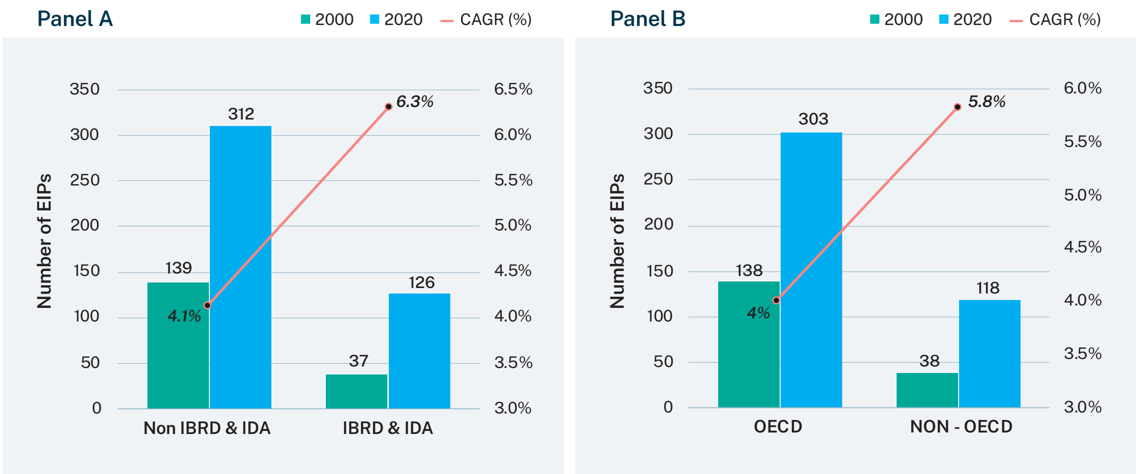
The World Bank survey conducted for this report found that the number of EIPs has been growing rapidly over the past two decades, with 245 (55.9 percent) out of 438 EIPs established since 2001 (figure ES. 2). Over the past two decades, the number of EIPs in countries outside the Organisation for Economic Co-operation and Development (OECD) grew by 5.8 percent annually — faster than in OECD countries (4 percent). EIPs in countries associated with the International Bank for Reconstruction and Development (IBRD) and the International Association (IDA) are growing even faster, at a compounded annual growth rate (CAGR) of 6.3 percent, than those in non-IBRD and non-IDA countries (figure ES.3). Overall, the average EIP score for the surveyed industrial parks, which is measured in terms of the number of EIP technologies in place, is 2.42. The adoption of EIP technologies, especially renewable energy, waste treatment, and industrial symbiosis technologies, has increased in non-OECD countries since 2001 (figure ES.4). Yet there is still a significant gap between developed and emerging economies in terms of the adoption of innovative infrastructure and service systems, technologies, and business models that promote EIPs and enhance resource circularity. A public sector presence in the ownership of industrial parks is still an important push factor for the adoption of EIP technologies and the promotion of the circular economy.

FIGURE ES.2 • Number of EIPs (1990–2020)



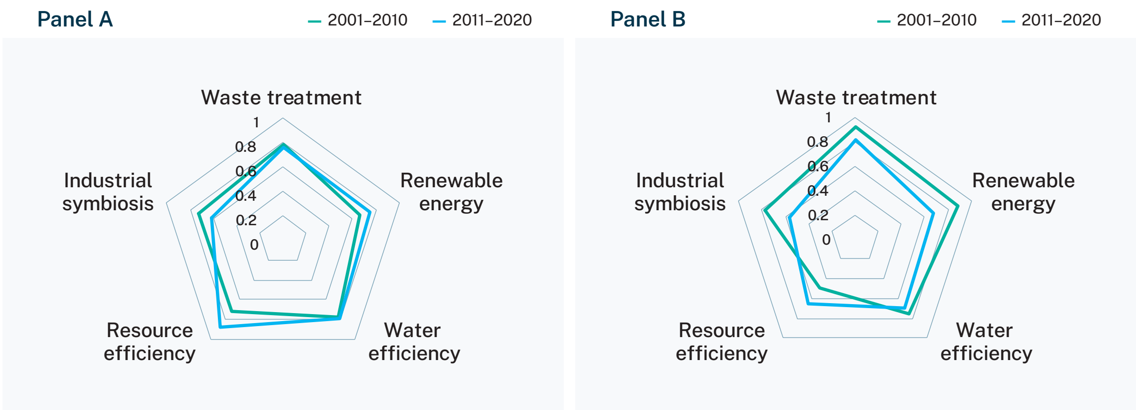
Note: Seventeen EIPs in the World Bank's database did not include information on their starting year of operations, and were therefore not included in this analysis. EIP = eco-industrial park; IBRD = International Bank for Reconstruction and Development; IDA= International Development Association.

FIGURE ES.3 • Compounded annual growth rate (CAGR) of EIPs between 2000 and 2020



Note: EIP = eco-industrial park; IBRD = International Bank for Reconstruction and Development; IDA= International Development Association. CAGR = compounded annual growth rate.

FIGURE ES.4 • EIP technologies in OECD and non-OECD countries



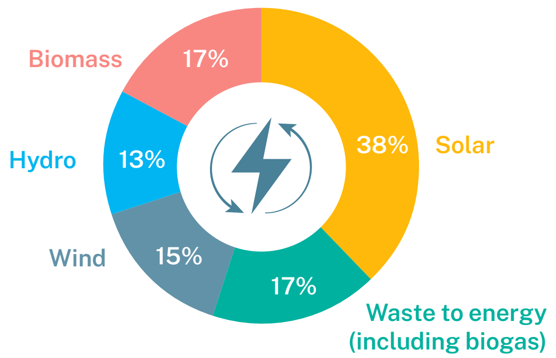
Note: EIP = eco-industrial park; OECD = Organisation for Economic Co-operation and Development. Numbers inside the graphs represent the simple probability that an EIP that starts an operation in the given range of years has the respective technology in the EIP survey year.

Industrial park developers and operators have vital roles to play in mainstreaming circular economy principles in industrial park operations by improving the circularity of energy, water, materials, and by-products during production processes. First, they can assess the "circularity gap" using the International Framework for Eco-Industrial Parks[1] and take actions to close it (for a selected list of performance indicators, see chapter 1, box 1.2). Based on the gap assessment, they can establish targets, a dedicated management unit, and even enforce legally binding agreements; coordinate knowledge exchange, data collection, and management; and promote trust among tenant firms by playing the role of a mediator as they communicate their varying interests and demands. Park developers and operators can also set up effective environmental performance monitoring systems and technologies, increase access to collective financing for tenant firms to develop common green infrastructure, and liaise with research institutions and governments to support research and development (R&D) activities to jointly invent new solutions or invest in testing facilities.

The report finds that improving energy management strategies at the industrial park level is essential for providing cleaner, low-cost, and reliable power supply to tenant firms (chapter 3). Improved energy management systems help enhance the competitiveness of industrial units by reducing energy and production costs as well as providing reliable energy (section 3.2). This report finds that park operators are integrating a service-based business model into their traditional real estate business model, though this is a trend that is observed mostly in OECD countries (57 percent of EIPs with energy management systems operate in OECD countries). Park operators can consider various energy management business models — energy performance contracting (EPC), energy supply contracting (ESC), and integrated energy contracting (IEC) — to avoid inefficient resource and energy consumption, mitigate GHG emissions, provide power supply to tenant firms at a competitive price, ad tap into new revenue streams. Park operators can also consider obtaining energy management system (EnMs) certification such as ISO 50001 to monitor and improve park-level energy efficiency performance, reduce operating costs, and meet or exceed investors' expectations. As implementing EnMS in industrial parks following international standards can be challenging due to the cost associated with it, national policies will be required to increase the uptake of EnMs, and transform the otherwise inefficient energy consumption of industrial parks and tenants.

Park operators can also integrate a circular economy approach by adopting low-cost renewable technologies. Various renewable energy sources can be integrated into captive power generation in industrial parks, including solar power, wind power, hydropower, waste-to-energy and biomass, geothermal, green hydrogen, and so on. This report finds that industrial parks have increasingly installed and invested in captive renewable energy plants, especially those involving solar PV (figure ES.5). To integrate solar energy, park operators consider mainly ground-mounted, rooftop-mounted, and floating panels. For instance, the World Bank Group is supporting the Bangladesh Economic Zone Authority (BEZA) to install all three types of solar panels with an installed capacity of approximately 90 megawatts peak (MWp) (see box 3.6 in chapter 3). This investment is expected to save more than 80,000 tons of CO_2 emissions, which is equivalent to that generated by more than 17,777 passenger cars.

FIGURE ES.5 • **Distribution of renewable energy source in 120 self-declared EIPs**



In integrating circular economy principles in their operations, park operators can also consider improving the efficiency of water use in EIPs through various technologies (chapter 4). Globally, 47.5 percent of 438 EIPs (or 208) surveyed have water efficiency improvement systems and technologies in place, which are mostly public owned and operated. But there is a critical gap in investment in such technologies in water-stressed regions, especially of low-income countries.

Water efficiency solutions can be implemented at two stages: that is, water supply and post-use (wastewater treatment). Water supply technologies featured in this report, such as **rainwater harvesting, desalination, and membrane technologies** can help minimize the withdraw and use of finite water resources (e.g., groundwater) by enabling increased utilization of renewable water sources (e.g., rainwater) and conventionally unusable water sources (e.g., saline water). **Advanced biological wastewater treatment technology, zero-liquid discharge (ZLD), and technologies that recover metals from wastewater** are important solutions that not only help minimize wastewater generation and remove pollutants but also increase wastewater reuse in industrial parks.

While some have high capital and operating costs, water efficiency technologies can generate economic benefits if good business models and operating schemes are developed. For example, in the Bursa Organized Industrial Zone, Turkey, treated wastewater from the wastewater treatment plant is sold, providing an additional source of income for the zone (box 4.2). A ZLD system installed in Hawassa Industrial Park in Ethiopia provides an economic return of $5–$13 for every $1 invested in water (see box 4.3). Park operators can also consider creating additional revenue generation opportunities through the alternate use of wastewater sludge. This would act as an additional enabler of water efficiency technologies, helping to cover investment and operating costs. Various government actions can help increase the adoption of these water efficiency technologies, including; effective legal and regulatory frameworks, as in case of Singapore for desalination technology, tariffs on the use of freshwater or financial incentives for setting up wastewater treatment plants, as in the Turkey case, and leveraging private investment through public-private partnerships, as in the case of India for ZLD technology.

Maximizing material and waste heat recovery and reuse is another important circular economy strategy that park operators can undertake to minimize waste generation (chapter 5). EIPs, especially involving mixed uses, encompass diverse industry sectors and processes. This provides an opportunity to utilize recovered material or waste heat from the production process of one plant as raw material or fuel for production processes in another plant — thus creating an industrial symbiosis network. There are two types of industrial symbiosis networks: those that interlink the functioning of the entire park to individual firms (**the zone-firm model**), and those that connect firms to other firms (**the firm-to-firm model**). Either way, there are clear economic, environmental, and social motivations for both park operators and tenant firms to create (or join) industrial symbiosis networks, as illustrated in various national EIP/industrial symbiosis programs in China, the Republic of Korea, Japan, and the United Kingdom. In Korea, for instance, the economic gains of industrial symbiosis projects implemented between 2005 and 2020 totaled $665 million.

The design of an industrial symbiosis project, including the choice of its technologies (e.g. high temperature pyrolysis, CO_2 recovery, and the Organic Rankine Cycle), **is highly dependent on the types and quantities of materials available within and around parks, and to what extent they can be recovered and reused. Park operators play an important role in establishing symbiotic relationships**, such as by undertaking various assessments to identify and prioritize potential industrial symbiosis opportunities. Park operators can partner with a third party to realize zone-to-firm industrial symbiosis projects, as in the case of the Vatva Industrial Estate in India (box 5.4). Additionally, park operators can improve awareness of good business cases among tenant firms through testing facilities or demonstration projects, as in Japan's Kitakyushu Eco-Town. They can also facilitate interaction among tenant firms to stimulate symbiotic opportunities, as seen in the extensive adoption of by-product exchange technology in Kwinana Industrial Park in Australia (box 5.5). While the number of industrial symbiosis projects is growing rapidly — 57.5 percent (or 252) of industrial parks surveyed by the World Bank Group have industrial symbiosis or resource efficiency measures in place, either solo or in combination — barriers still exist in implementing industrial symbiosis projects. These barriers include, for instance, the lack of access to information on material availability and economically viable options. To address these barriers, governments can provide **incentives, devise innovative digital tools or platforms, and provide financing mechanisms**. In particular, a range of innovative digital tools and platforms are being developed globally to support park operators and firms in identifying industrial symbiosis opportunities and assessing their technical and economic feasibility, as illustrated by the smart closed-loop grid system in Korea (box 5.2).

In summary, to accelerate the adoption of circular economy principles, industrial park operators need to:

» ***Tailor technical designs to local contexts while maximizing the efficient use of existing infrastructure.*** Circular economy strategies introduced in this report are not one size fits all; their technical viability varies according to the availability of technologies, as well as a range of other enablers and limitations identified on the ground.

» ***Create joint value through collaboration.*** Promoting stakeholder collaboration is key to developing innovative, locally tailored, and technically and economically workable circular economy solutions. Key stakeholders in the process of mainstreaming circular economy solutions at the park level include park developers and operators, tenant firms, industrial associations, local suppliers, infrastructure operators, national and local governments, service or technology providers, and financial sector stakeholders.

» ***Revisit existing business models and pilot innovations.*** Industrial park operators need to navigate and build new business models to mainstream circular economy approaches. These include providing additional services such as negotiating contract agreements and catalyzing public-private partnerships for infrastructure investments. Creating a good business case includes envisioning park operators' new roles as service providers, and rethinking parks' circular economy strategies from the broader perspective of integrated energy, water/wastewater, and waste management plans.

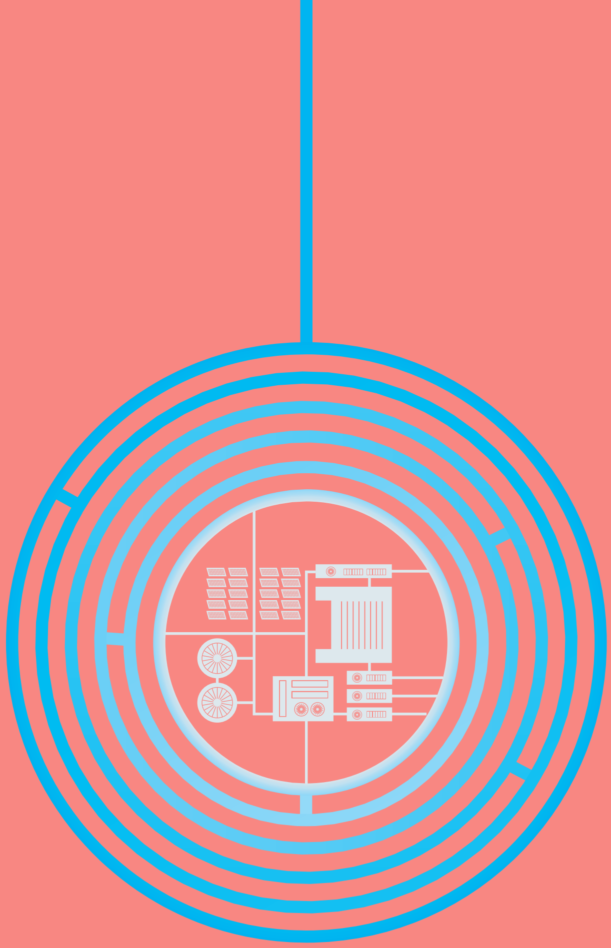
» ***Strengthen institutional capacity and skills competence.*** The status of existing infrastructure systems, institutional capacity, and the availability of skilled operators are critical concerns. Park operators in developing countries may not always have in-house capabilities and the ability to design, maintain, and operate infrastructure that features novel technological designs. In these contexts, technical assistance, including the skills training of park operators, technology providers, and relevant government agencies, would be required.

» ***Leverage digital technologies and platforms.*** Digital access and engagement can boost markets not only for new, and preferably green, products, but also services, underused assets, secondary materials, and human capital.

While their role is important, park operators cannot implement all these actions alone. Policy and financial incentives are critical to addressing barriers and creating synergies among various circular economy solutions adopted within and across industrial parks. Development partners, including the World Bank Group, which is already working with its client countries to track and build business cases in these areas, can support client countries and park operators to mainstream circular economy principles in industrial park operations. Next steps include developing more case studies and pilots to identify, evaluate, and monitor the implementation of various technologies featured in this report, as well as to identify innovative technologies and good business models.

Endnotes

1. To download the framework, version 2.0, please go to: https://openknowledge.worldbank.org/handle/10986/35110.



Circular economy principles can significantly enhance the competitiveness of industrial parks. Among other options, eco-industrial park models and technologies can help integrate these principles in park development and operations.

1 The circular economy: A new competitiveness agenda for industrial parks

1.1 • The circular economy and its importance for industrial parks

Industrial parks have served as a springboard for industrial development, allowing countries and their industries to focus development efforts on specific locations and spaces. Such parks range in nature from simple real estate developments to more complex, specialized regimes with focused policies and services for tenant firms. Though the names of such parks vary depending on the policy or branding priorities of countries, those that have relatively less regulation are typically called business parks or industrial estates/parks/clusters. Those with more specialized regulations, such as customs regimes, incentives, and specialized business services, tend to be known as special economic zones (SEZ),[1] economic zones (EZs), or export processing zones (EPZs). Specialized industrial parks, including SEZs, have been utilized as engines of industrial growth by more than 140 economies around the world, including more than 100 developing and transition economies. As of 2019, there were nearly 5,400 SEZs globally with at least 500 more in the pipeline (UNCTAD 2019). Nearly 1,000 of these had been established in the preceding five years, indicating the popularity of this industrial development model.

The economic gains of industrial parks can come at a loss of environmental quality within and around their location; this can eventually affect the reputation and competitiveness of the parks and their tenant firms. Environmental issues include unsustainable energy, water, wastewater, and waste management, in addition to direct and indirect air pollutant emissions, odor, and noise. High energy consumption and water shortages are becoming increasingly severe, presenting a possible threat to the development and operation of industrial parks. Similarly, with growing production and consumption, waste management practices need to be upgraded.

BOX 1.1

What is the circular economy?

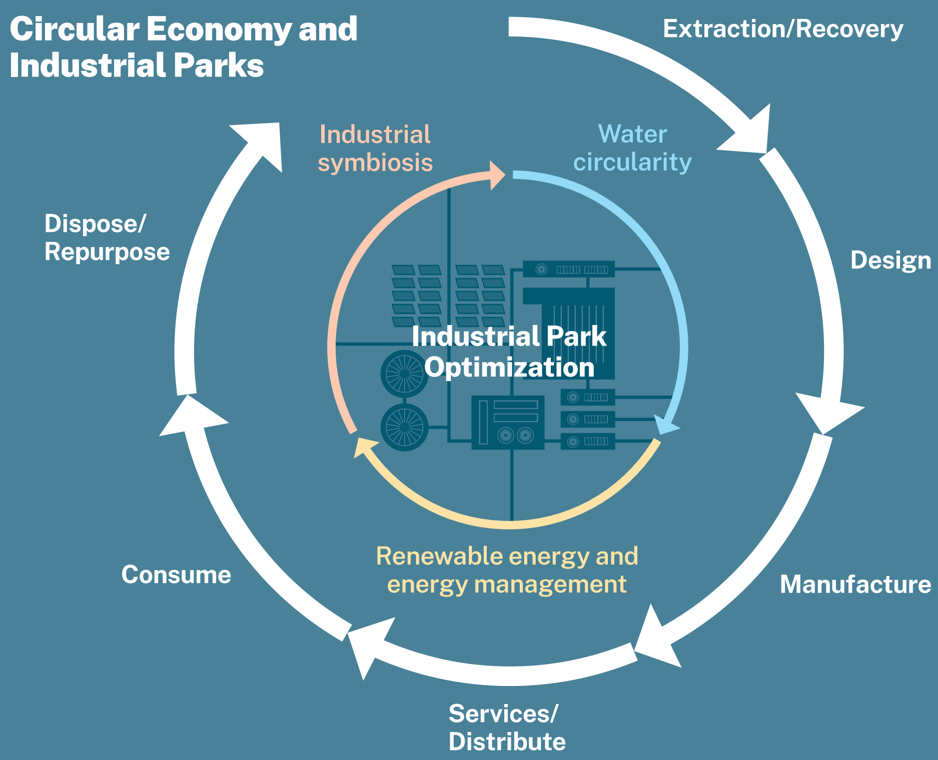
The circular economy approach can be defined as a paradigm shift from the existing linear "take-make-dispose" model. At the systems level, it aims to close resource loops to minimize finite resource consumption, waste, and pollution (Ellen MacArthur Foundation 2019). Its "reduce-reuse-recycle" model hinges on three principles: (1) "design out" waste and pollution wherever possible, (2) retain products and materials by extending their life, and (3) regenerate natural systems by going beyond waste management and recycling and integrating these principles in applicable solutions and practices (Ellen MacArthur Foundation 2020).

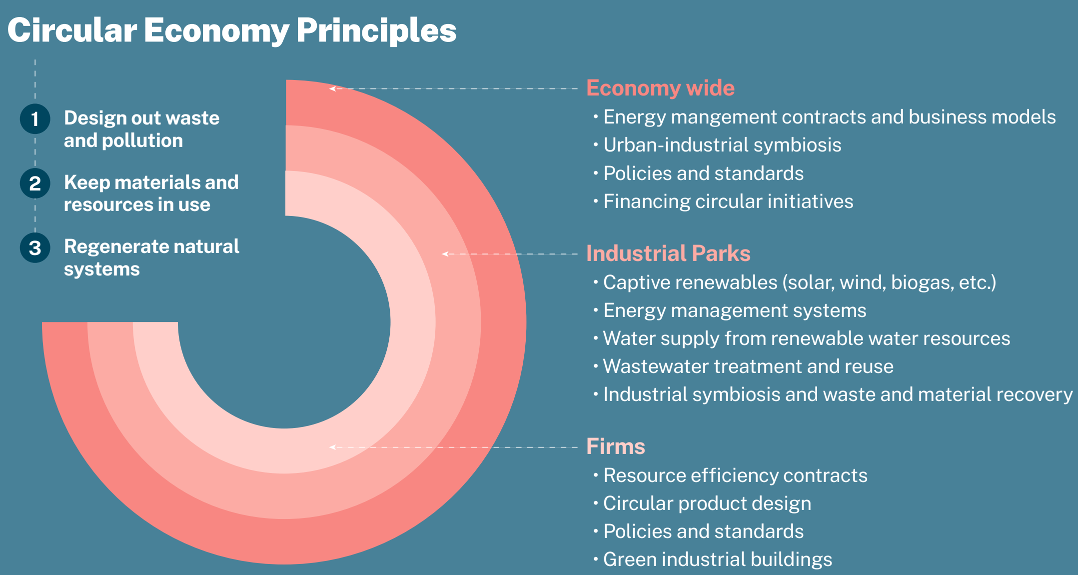
The practice of the circular economy is hence a transformative way to decouple economic growth from the loss of environmental value and carbon- and resource-intensive industrial development. It includes practices such as eco-design of products to ensure durability, reusability, upgradability, and reparability, addressing hazardous chemicals and enhanced energy and resource efficiency in a systemic way. It also features the reuse of parts, components, and materials; repairs, refurbishments, and remanufacturing to keep products in use; recycling to extract materials for reuse; and recovering energy from nonrecyclables.

Industrial parks can adopt a combination of different strategies to foster the circular economy:

- Promoting higher renewable energy generation and use, and achieving carbon neutrality
- Investing in common infrastructure and service provision to optimize the use of resources (e.g., steam networks, CO_2 recovery plants, cogeneration/trigeneration using biomass and/or biogas)
- Keeping materials and resources in use at the park level by encouraging tenant firms to create a symbiotic network and enabling their waste and by-product exchange
- Designing waste out by encouraging tenant firms to integrate circular designs and to use environmentally friendly technologies in their production facilities
- Fostering the establishment of recycling enterprises and sorting facilities rendering services to tenant firms
- Rethinking business models for improved energy, water, and waste management at the park level
- Harnessing digital technologies to increase resource circularity and material exchange

FIGURE 1B.1 • Circular economy principles applied in industrial parks





Industrial parks feature a wide range of industry sector profiles that have large energy and carbon footprints. As of 2017, the iron and steel, cement, chemical, and petrochemical sectors still accounted for 37 percent of global final energy consumption and 24 percent (or approximately 8.5 gigatons) of global carbon dioxide (CO_2) emissions (IEA 2020). Material reuse, meanwhile, has been decreasing in these sectors: in 2019, only 8.6 percent of 100 billion tons of materials extracted were reused, down from 9.1 percent in 2017. In 2017, material extraction, processing, and production contributed to 62 percent of all greenhouse gases emitted (excluding emissions from land use, land use changes, and forestry) (Circle Economy 2019). Looking ahead, between 2011 and 2060, the growth of material use is projected to increase 4.2 times in Africa and 2.1 times in Asian countries that are not part of the Organisation for Economic Co-operation and Development (OECD) countries, compared to an average of 1.6 times for other regions. **All of these data points suggest that significant efficiencies can be unlocked through the pursuit of circular economy principles in industries and industrial parks.**

Eco-industrial parks (EIPs) are a new category of zones that implement measures to improve their environmental, economic, park management, and social performance. Traditionally, investments made to reduce firms' environmental impacts were viewed as an additional expenditure with limited commercial benefit. This viewpoint is changing, and sustainability measures have moved from being optional to necessary for the commercial success of companies in industrial parks. A 2015 study showed that, by 2030, the application of circular economy principles could generate annual cost savings of $700 billion and improve resource productivity by 3 percent in Europe alone (McKinsey 2017). Thus, the concept of the circular economy has considerable implications for the sustainable development of industrial parks.

The efficiency gains and cost savings achieved by merely complying with higher environmental standards no longer offer a viable competitive advantage, considering market trends. Sixty-six percent of 30,000 global respondents in 60 countries cited their willingness to pay more for sustainable goods, in 2019 up from 55 percent in 2014. In the United States, specifically, high Environmental and Social Governance (ESG) awareness drives 75 percent of consumer purchase decisions (HSBC Global Research 2019). The adoption of closed-loop models (e.g., platforms for resource sharing, recovery, and recycling) is estimated to be a business opportunity worth $4.5 trillion globally by 2030 (Accenture Consulting 2015). In response to market demand, a growing number of manufacturing companies — including Apple, Proctor & Gamble, Danone, Nestle, and others — are trying to transform material supply chains, and expect their many partners and suppliers to follow suit. Multinational brands (e.g., Unilever, Nike, Puma, Evian) with influence over plastics value chains are, for example, significantly increasing their commitment to using recycled plastics. Top-tier manufacturing firms are therefore increasingly looking for suppliers and/or industrial parks that can help them integrate circular economy principles across their supply chains. These data point to the fact that **applying circular economy principles is an important means to improve the competitiveness of manufacturing companies. The application need not be limited to individual manufacturing units: there is a significant scale-up opportunity in the upstream and downstream value chains as well as other sectors that affect how these value chains operate.**

Targeted industrial park interventions provide a cost-effective approach to enhancing circular economy practices in a synergistic manner across a broad range of sectors. Circular economy principles can be effectively implemented at the company or consumer level, industrial park level, and macro level (municipality, province, and country), and across various sectors — stretching beyond industry to urban development, agriculture, energy, and transport. Industrial parks often host a range of industrial sectors and tenant firms, managed or regulated by national and municipal governments, and have backward and forward linkages with domestic industries. They consume large quantities of water and energy resources while at the same time generating waste. The agglomeration of industries, as well as the environmental and social externalities associated with industrial production, presents an ideal opportunity to introduce circular economy principles.

Targeting industrial parks that house multiple manufacturing units can provide the requisite push to adopt circular economy principles. By integrating these principles, industrial park operators and tenant firms can reduce resource consumption and operational costs, and hence increase their competitiveness significantly. For example, by diversifying and optimizing power demand and supply, which includes electricity generated from captive renewable-based power plants, industrial parks and tenant firms can significantly reduce energy costs and greenhouse gas emissions and hence increase green competitiveness (see chapter 3).

Implementing circular economy principles in industrial parks requires innovative approaches, leveraging EIP models and technologies. These include but are not limited to, enhancing the use of renewable energy sources, industrial symbiosis, wastewater treatment and reuse among firms and at the industrial park level, recovery of waste heat in industrial processes, and solid waste valorization as a substitute raw material. To promote synergies through a planned approach, governments, companies, and international organizations can build upon concepts and frameworks that already exist, such as EIPs.

1.2 • Eco-industrial parks are building blocks of a circular economy

EIPs are an effective means to achieving a circular economy and increasing the competitiveness of firms and industry sectors. "EIPs can be defined as industrial areas that promote cross-industry and community collaboration for common benefits related to economic, social and environmental performance" (World Bank, UNIDO, and GIZ 2021). EIPs enhance the circularity of resources critical to industrial processes (water, energy, materials, and waste, etc.) by significantly reducing dependence on depletable resources like fossil fuels. They promote the recycling and reuse of resources and waste, as well as industrial symbiosis and renewables/bio-based inputs. In the process, tenant firms can achieve more cost-efficient production that is also resilient to price fluctuations and resource scarcity. Ultimately, EIPs can support the greening and decarbonization of value chains, as well as improve resource management and conservation, through their focused circular economy interventions.

The International Framework for Eco-industrial Parks is an essential tool for park operators (World Bank, UNIDO, and GIZ 2021). The framework, developed jointly by UNIDO, the World Bank, and GIZ, outlines minimum requirements and performance expectations of an EIP. Circular economy principles are embedded in the framework's environmental performance requirements, as outlined in box 1.2. By meeting these requirements, park operators can, by default, integrate circular economy principles in their industrial park operations.

Integrating circular economy principles in industrial park development and operations requires new technologies and business models that provide state-of-the-art infrastructure and services at optimized costs. For example, a zero liquid discharge (ZLD) system built into wastewater treatment and reuse systems uses reverse osmosis and ultrafiltration to channel wastewater back to industries. Waste heat (steam) can be also recovered from steel manufacturers, transported through a steam "highway" and reused by chemical or textile industries. Investment in industrial symbiosis technology and infrastructure generates revenue and cost savings for both tenant firms and local governments, creating a new business model for industrial production.

1.3 • Objectives

This report aims to provide industrial park developers and operators and policy makers with insights into the innovative technologies being used in EIPs that may, in turn, be used to help mainstream circular economy practices in industrial parks. The penetration of sustainable and low-carbon technologies in industrial parks is far greater in developed economies than developing ones, partly due to a lack of information about these technologies and their cost savings. This report aims to fill this gap and help practitioners understand the business case for undertaking circular practices, as well as to provide information critical to making related investment decisions. The report provides:

» **An overview of latest trends, innovative technologies, and practices adopted in EIPs** globally that may help to mainstream circular economy principles in energy, water, and waste/material management

» **An elaboration of the benefits and challenges of various EIP technologies**, along with their financial implications (capital and operating expenditures, and internal rate of return) and possible revenue streams through real-life case studies

» **Policy recommendations to ensure the wider uptake of innovative technologies and business models** by focusing on market development, technical capacity enhancement, and improved access to finance for each technology.

The intended audience for this report is industrial park operators and national/subnational policy makers for industrial infrastructure.

1.4 • Methodology

This report uses a mixed research method to identify how EIP technologies can help integrate circular economy approaches in industrial parks and make parks more competitive. The following steps elaborate the methodology:

» In order understand the latest trends in EIPs and technologies adopted, the World Bank team behind this report has conducted an extensive desktop and online survey of industrial parks that are either well known as EIPs or have defined themselves as such. In addition, the team considered industrial parks of countries that have employed some form of advanced environmental technologies. The identified list of industrial parks was reviewed based on the environmental performance requirements established under the International Framework for Eco-industrial Parks. Research was conducted independently of existing databases: every single industrial park that is either planned or operating in a country was researched and verified to the extent possible.[2]

» The surveyed industrial parks were assessed using a scoring methodology. This report identifies common infrastructure that allows for better energy, water, and material and waste management performance at the park level, and specific technologies that, for example, promote water use efficiency or industrial symbiosis. To assess the degree to which EIP technologies have been implanted in an industrial park:

- A score of 1 implies **minimum** implementation, or at least one EIP technology.
- A score of 2 means **adequate** implementation, or at least two EIP technologies.
- A score of 3 means **extensive** implementation, or more than two EIP technologies.

» The World Bank team also interviewed the operators of several industrial parks to better understand the details of the technical systems and business models, and how they are leveraging EIP technologies.

The resulting report is not without limitation. Industrial parks that have adopted EIP technologies may have been overlooked. Industrial parks with limited information on EIP interventions and technologies were excluded. Therefore, the list of industrial parks identified as EIPs may not cover the entire number of EIPs operating around the world. Some EIPs are designed and operated more as clusters, industrial districts, or voluntary networks that are embedded in a larger spatial landscape. These types of EIPs do not have centralized, on-site management entity within a limited physical boundary, and do not meet the traditional definitions of EIPs. Even so, they were included in this report, since efforts to mainstream circular economy principles often reach beyond the physical boundaries of industrial parks.

The report offers a granular and practical overview of the global EIP space and brings to light the technologies, approaches, and business strategies being employed to make resources used in industrial parks more circular and cost-effective. It intends to facilitate an enhanced understanding of innovative technologies, interventions, and business models that enable the adoption of the circular economy in industrial park operations. Thus, it provides a benchmark for assessing operational approaches based on a deeper understanding of what has or has not worked. Further analysis of the technologies being employed and their specific contexts would be useful to inform decision-making.

1.5 • Structure of the report

The report highlights EIP technologies, infrastructure investments, and business models in the following three areas: energy (primarily renewable energy technologies), **water** (water supply and wastewater treatment technologies), and **material and waste heat** (industrial symbiosis and other material recovery technologies). For each technology type, examples and case studies provide readers with a realistic view of the costs involved, potential benefits, applicable business models, challenges, and solutions. The report constitutes the following chapters:

Chapter 1 — The circular economy: A new competitiveness agenda for industrial parks

This establishes the importance of an industrial park in economic development and how circular principles can help enhance their competitiveness, thereby improving the prospects of economic development.

Chapter 2 — Mainstreaming circular economy approaches through EIP technologies: Latest trends

Data mined from a global survey of EIPs are presented, along with key trends related to practices and technologies that promote the circular economy in and around industrial parks.

Chapter 3 — Energy

This chapter identifies prevalent technologies, business models, and technical enablers relevant to energy management. It discusses different types of energy management strategies and business models that industrial parks have implemented to increase their competitiveness and sustainability, while responding to various constraints or opportunities created by national and local energy regulations. The chapter also outlines captive renewable energy solutions and technologies that can be implemented in industrial parks, including solar generation and storage, wind, and waste-to-energy sources.

Chapter 4 — Water

This chapter highlights the ways in which park developers and operators can help enhance water and wastewater reuse in industrial parks through an innovative combination of wastewater treatment and water supply technologies. These technologies include rainwater harvesting systems, desalination plants, membrane technologies, and advanced biological wastewater treatment technologies such as ZLD systems.

Chapter 5 — Material and waste heat recovery

This chapter focuses on strategies and technologies used in promoting the recovery, exchange, and reuse of materials and waste heat that can substitute primary raw materials; reducing structural waste through the optimal design and use of underutilized resources and assets (infrastructure, buildings, and space); and reducing the overall volume of waste and GHG emissions generated by industrial parks, tenant firms, and local firms in the supply chain.

Chapters 3–5 feature on overview of relevant resource use in EIPs, followed by a brief technical description (along with a schematic diagram, where applicable), implementation and financial considerations, case studies, operational challenges, key enablers, key takeaways for park operators, and policy recommendations.

Chapter 6 — Future prospects

This chapter summarizes key lessons and recommendations drawn from the global survey of EIPs and the case studies of international practices, and discusses areas for further improvement.

BOX 1.2

The International Framework for Eco-industrial Parks

AN ESSENTIAL TOOL TO MAINSTREAM CIRCULAR ECONOMY PRINCIPLES IN INDUSTRIAL PARKS: The International Framework for Eco-industrial Parks outlines minimum requirements for a park's environmental, social, and economic performance, as well as overall management, that must be fulfilled for the park to be considered an EIP. Circular economy principles are embedded in the environmental performance requirements of this framework. These requirements are related to pollution prevention; resource efficiency and clean production; industrial symbiosis and synergies; and water, waste, and energy management. The performance requirements relevant to circular economy principles are summarized in table B1.2.1.

TABLE B1.2.1 • Selected environmental performance requirements of the framework

SUBTOPIC	PERFORMANCE REQUIREMENTS*
MANAGEMENT AND MONITORING	
Environmental/ energy management systems	• Firms have functioning and fit-for-purpose EMS/EnMS systems. Summary information from these management systems is provided to park management, who aggregate and report on data at the park level. • A summary of data from firms' EMS/EnMS systems to be provided to park management, for aggregation at the park level • 10% of firms' energy consumption covered by an energy management system
ENERGY	
Energy network and waste heat recovery	• A program/ mechanism is in place to identify opportunities for common energy and heat exchange networks to be established. The park management will provide the required physical network and offers support programs to assist resident firms with implementation.
Renewable and clean energy	• The industrial park leverages available renewable energy with plans to increase its contribution for shared services (e.g., solar streetlamps). Total renewable energy use for electricity and heat production in the industrial park is equal to or greater than renewable energy share in the annual national electricity mix in the grid.
Energy Efficiency	• Energy efficiency opportunities should be identified at the park and firm levels to reduce energy use and associated greenhouse gas emissions. EIPS should identify and promote technological ad process-related interventions in their own and resident business operation. The equivalent of at least 10% of the total CO_2 emissions (scope 1 and 2) is covered by the percentage of firms that have a qualified energy efficiency certification (LEED, Industry EDGE, German Sustainable Building Council (DGNB) or ISO 50001 or their national equivalent).
WATER SUPPLY AND WASTEWATER	
Wastewater treatment/ Water efficiency, reuse and recycling	• The park and firms have systems in place to increase water savings and reuse. • 100% of industrial wastewater generated by industrial parks and resident firms is treated in accordance with appropriate environmental standards. • 25% of total industrial wastewater from firms is reused responsibly within or outside the industrial parks.
WASTE AND MATERIAL USE	
Waste/ by-products reuse and recycling	• A waste management plan with a program/ mechanism in place to promote and encourage reuse and recycling of materials by firms in the park (for example, raw materials for process and non-process applications). 25% of nonhazardous, solid industrial waste generated by firms is reused/recycled by other firms, neighboring communities, or municipalities.
Resource conservation	• The park management and firms are obliged to consider circular economy principles and practices (e.g. circular products, using as little virgin raw material as possible, reuse and remanufacturing of components and parts and making extensive use of secondary/ recycled materials generated in the park). • 20% of manufacturing firms adopt circular economy practices, including engagement in Industrial Symbiosis Networks in the park; or actively exchanging secondary raw materials, or waste, or other circular economy practices.
CLIMATE CHANGE AND THE NATURAL ENVIRONMENT	
Air, GHG emissions, and pollution prevention	• The park seeks to limit and mitigate pollution and GHG emissions, including air, waterway, and ground pollution. A set of measures at the park level is introduced (for instance, low-carbon technologies, energy efficiency measures, circular economy practices, waste heat recovery) to reduce GHG emissions. • 50% of firms in park which have pollution prevention and emission reduction strategies to reduce the intensity and mass flow of pollution/ emission releases that exceed national regulations.

Source: World Bank, UNIDO, and GIZ 2021.

Note: *Performance requirements include both prerequisites and performance indicators. This table does not make a distinction between the prerequisites and performance indicators.

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Endnotes

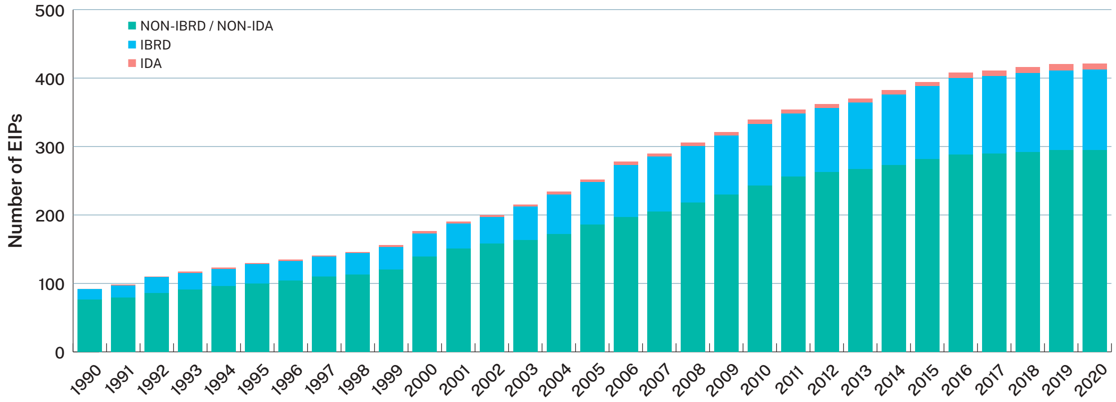
1. SEZ is the most common term for specialized industrial parks worldwide. Other terms tend to be specific to certain countries (e.g., EPZ in Bangladesh).
2. For example, the desktop research used an extensive word search for any industrial park that may employ EIP technologies, in the relevant language (e.g., Portuguese for Brazil, and Spanish for Argentina).

2 Mainstreaming circular economy approaches through EIP technologies: Latest trends

2.1 • Latest trends across eco-industrial parks (EIPs)

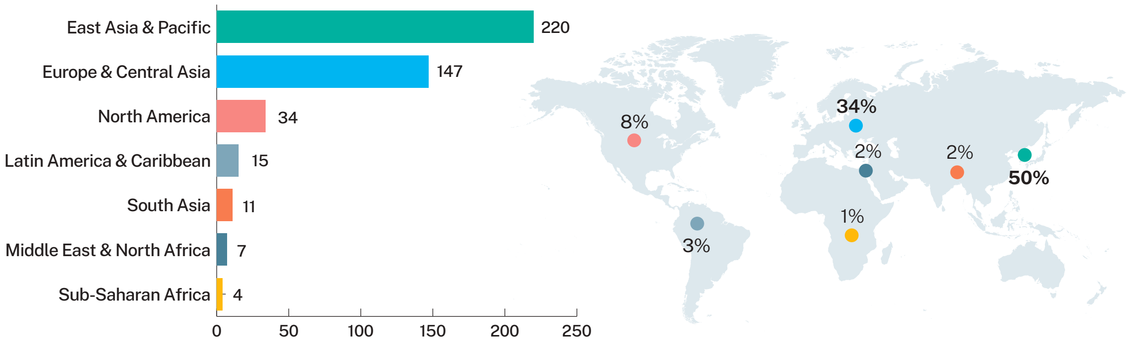
The number of EIPs has grown rapidly over the past two decades (figure 2.1). Among the total number of industrial parks surveyed, 438 industrial parks were identified as EIPs based on the scoring method. Overall, more than 245 EIPs have been established since 2001. These include industrial parks that have been transformed into EIPs with new technologies and infrastructure investments, as well as newly established industrial parks with advanced features. More than half of the surveyed industrial parks operate in countries of the Organisation for Economic Co-operation and Development (OECD), with the largest number present in Europe and the East Asia and Pacific region (34 percent and 50 percent, respectively) (figure 2.2).

FIGURE 2.1 • Number of EIPs (1990–2020)



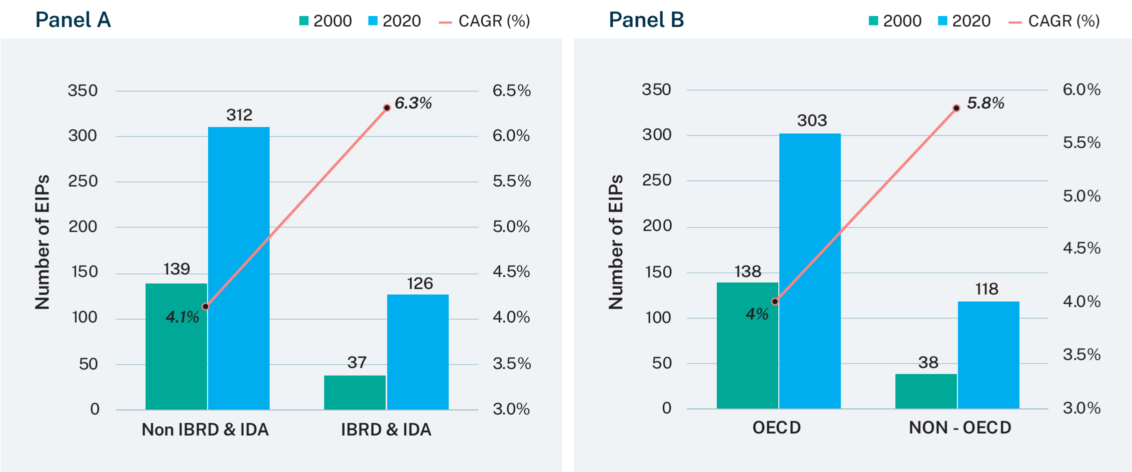
Note: Seventeen EIPs in the World Bank's database did not include information on their starting year of operations, and were therefore not included in this analysis. EIP = eco-industrial park; IBRD = International Bank for Reconstruction and Development; IDA= International Development Association.

FIGURE 2.2 • Geographical distribution of EIPs



EIPs are growing relatively faster in IDA, IBRD, and non-OECD countries (figure 2.3). Nearly 71 percent (312 EIPs) of the surveyed EIPs, operate in countries not associated with the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA), whereas only 28.7 percent (126 EIPs) are in IDA and IBRD countries. Though smaller in numbers, EIPs in IDA and IBRD countries are growing relatively faster: between 2000 and 2020, they grew at a compounded annual growth rate (CAGR) of 6.3 percent in IBRD and IDA countries, but only 4.1 percent in non-IBRD and non-IDA countries (figure 2.3, panel a). During the same period, EIPs grew at a compounded annual growth rate (CAGR) of 5.8 percent in non-OECD countries and 4 percent in OECD countries (figure 2.3, panel b).

FIGURE 2.3 • Compounded annual growth rate (CAGR) of EIPs between 2000 and 2020



Note: EIP = eco-industrial park; IBRD = International Bank for Reconstruction and Development; IDA= International Development Association. CAGR = compounded annual growth rate.

The World Bank survey also shows that EIPs can generate a large number of jobs—on average, they generate 14,731 jobs. EIPs in the East Asia and Pacific region are associated with 15,725 jobs, while those in Europe and Central Asia generate 14,295 jobs and in North America about 4,721 jobs on average.

The World Bank survey highlights that EIPs are often developed and operated by public sector park operators (various park management models can help accelerate the adoption of circular economy principles and related technologies; see box 2.1). Of the 438 identified EIPs, approximately 67 percent are currently owned and managed by public operators, 23 percent are privately owned and managed, while the remaining 10 percent are initiated and maintained through public-private partnerships (PPPs) (figure 2.4). Between 2000 and 2020, the number of public, private, and PPP-type EIPs increased by 4.8 percent, 3.4 percent, and 5.2 percent, respectively. The percentage of public EIPs is higher (68 percent) in IBRD countries than in non-IBRD countries (57 percent), whereas the percentage of privately owned and operated EIPs is higher in non-IBRD countries (32 percent). EIPs managed through a PPP mechanism are roughly the same in both IBRD and non-IBRD countries (10 and 11 percent, respectively).

BOX 2.1

Industrial park management models used in operating EIPs

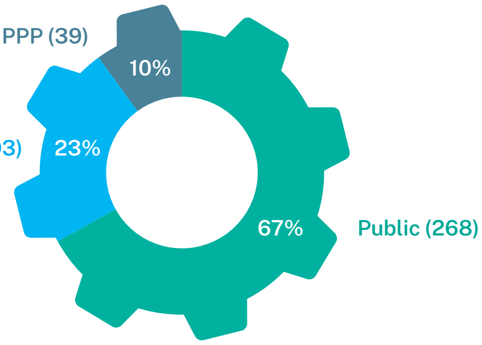
A number of industrial park management models can be applied in the integration of circular economy approaches in eco-industrial parks. These models include the following.

- **Associative management:** The parks' resident companies organize themselves into an association to manage one or more industrial parks with minimal intervention from the government.
- **Government management:** A dedicated team assigned from national, regional, provincial, or municipal authorities manages the industrial park.
- **Public-private management:** A government-managed industrial park receives support from a private contractor, nongovernmental organizations, associations, or foundations facilitating a cooperative approach to service provision, shared between a city and the private sector. The arrangement can be permanent (e.g., a government liaison officer is a permanent staff member, while the private company provides the other industrial park management positions) or temporary (e.g., the private sector is part of a capacity-building process until the government can perform all industrial park management functions).
- **Private management:** Private legal entities or real estate agents establish or manage the industrial park. Revenue generation forms their core objective, which is typically achieved by renting out plots of land or charging fees for infrastructure or services.

In all the models, there is a separate park-level management body that is responsible for park operations as well as maintenance of common infrastructure. The seat of this park-level body can be in the park itself (i.e., on-location park management) or at a national/subnational level (i.e., off-location park management).

More than 80 percent of EIPs have an on-site park management entity, regardless of the ownership type (public, private, PPP, or state owned). According to the International Framework for Eco-industrial Parks (UNIDO, World Bank, and GIZ 2021), an empowered park management entity must exist to plan, operate, manage, and maintain common infrastructure and utility services provided to resident firms. Through this distinct, functional park management, EIPs can ensure that functioning environmental management systems and energy management systems are in place, as well as other supporting programs, documents, and plans on industrial heat recovery, water reuse, or monitoring, mitigating, and/or minimizing greenhouse gas (GHG) emissions.

FIGURE 2.4 • Park ownership characteristics of surveyed EIPs



Note: The total number of EIPs with park management was 400, of which 38 cases did not have park ownership or management information. EIP = eco-industrial park; PPP = public-private partnership.

2.2 • Technologies promoting a circular economy in the surveyed EIPs

A wide variety of technologies have been adopted in the surveyed EIPs which serve as essential building blocks for the transition to a circular economy. These technologies and practices, which have a direct impact on reducing the use of virgin resources, have been considered for this assessment in three areas — energy,[1] water, and material and waste heat — in line with the International Frameworks for Eco-Industrial Parks Version 2.0 (UNIDO, World Bank, and GIZ 2021). This collective set of technologies (given below) are referred to as “EIP technologies” hereon.

Energy:

- Energy management system
- Solar power
- Wind power
- Biomass and waste-to-energy

Water:

- Sustainable water supply
- Wastewater treatment
- Heavy and valuable metal recovery from wastewater

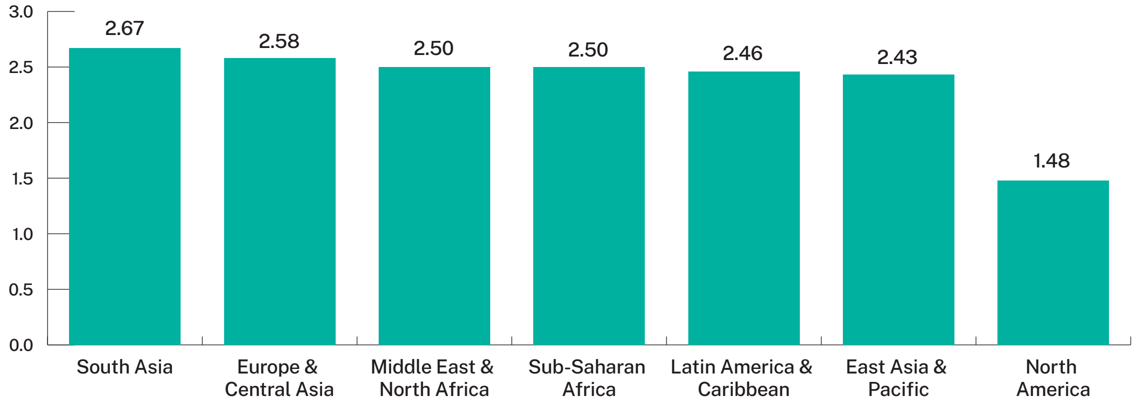
Material and waste heat:

- Industrial symbiosis
- Material and energy recovery

Overall, the average EIP score for the surveyed industrial parks, which is measured in terms of the number of EIP technologies in place, is 2.42. This means that most of the EIPs in the World Bank database are adopting more than two technologies that can help them scale up circular economy approaches in industrial parks. **Europe and Central Asia (ECA) and South Asia are the leading regions in terms of the level of adoption of various EIP technologies,**[2] with average EIP scores of 2.67 and 2.58, respectively (figure 2.5). While there are 220 EIPs in the East Asia and Pacific (EAP) region, its average EIP score is relatively lower (2.43). Similarly, the average EIP score is lower in non-OECD countries (2.11) than in OECD countries (2.50) (figure 2.6).

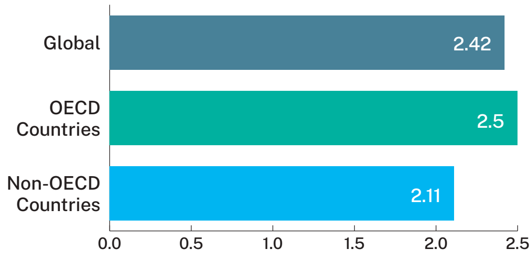
EIPs managed by a PPP have a higher EIP score overall (2.54) (figure 2.7), especially in high-income countries. In upper-middle-income countries, privately owned and operated EIPs have a higher EIP score on average (2.44), while in lower-middle-income countries publicly owned and operated EIPs have the highest score (2.57).

FIGURE 2.5 • Average EIP score by region



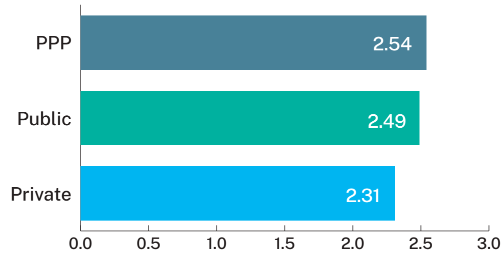
Note: The EIP score equals 1 when an industrial park has at least one technology promoting the circular economy, 2 when the EIP has implemented two technologies, and 3 when the EIP has three or more technologies. EIPs with no information on their available technologies, do not get an EIP score. Out of the total 438 surveyed EIPs, 354 have an EIP score. EIP = eco-industrial park.

FIGURE 2.6 • The average score for surveyed EIPs (OECD and non-OECD countries)



Note: EIP = eco-industrial park; OECD = Organisation for Economic Co-operation and Development.

FIGURE 2.7 • EIP score by type of park ownership

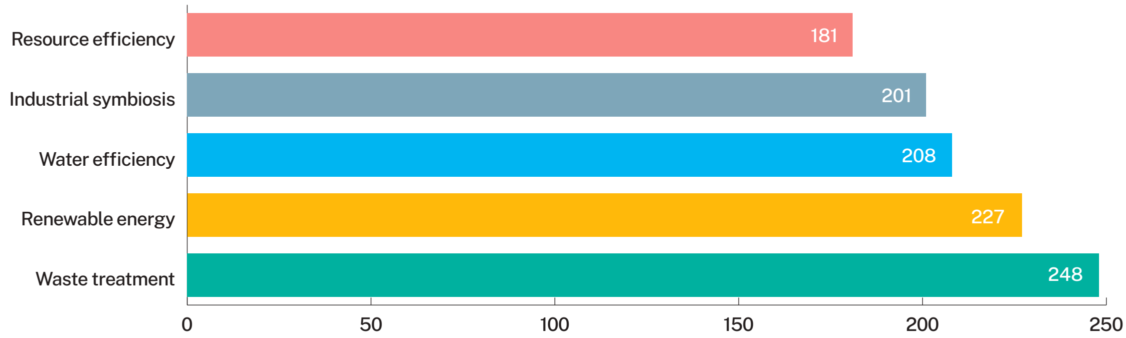


Note: EIP = eco-industrial park; PPP = public-private partnership.

The results provide key insights related to the adoption of technologies across regions:

1. Waste treatment and renewable energy technologies are widely adopted in EIPs.
The World Bank survey has identified 227 EIPs (51.8 percent of the total number of EIPs) deploying renewable energy technologies, and 248 EIPs (56.6 percent) using waste treatment technologies (figure 2.8). Adoption of waste treatment and renewable technologies is higher among the surveyed EIPs than resource efficiency (41.3 percent), industrial symbiosis (45.9 percent), and water efficiency (47.5 percent) technologies.

FIGURE 2.8 • Distribution of technologies promoting circular economy in the surveyed EIPs

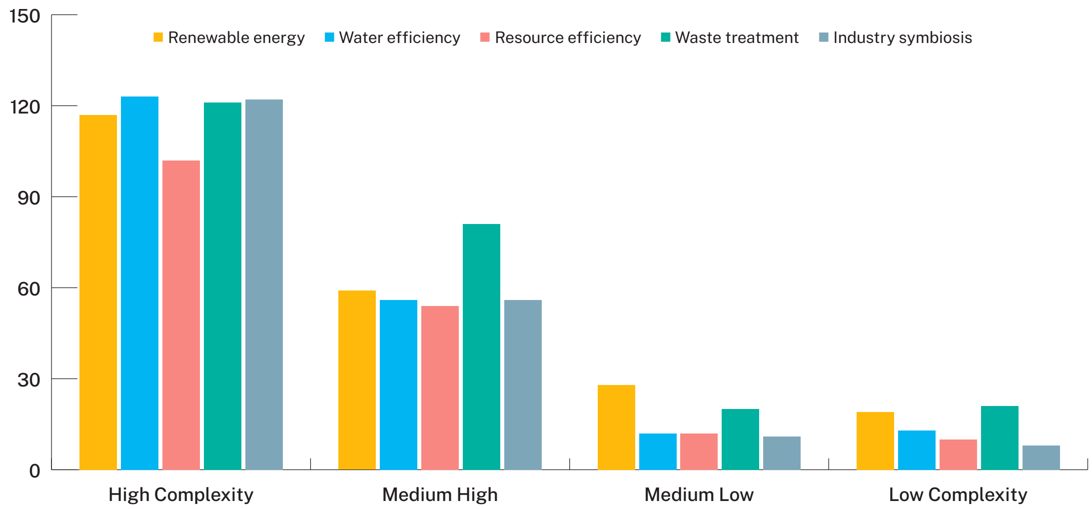


Note: The surveyed EIPs had adopted more than one technology. EIP = eco-industrial park.

2. A significant gap exists in the adoption of EIP technologies between countries with high economic complexity and those with low economic complexity.

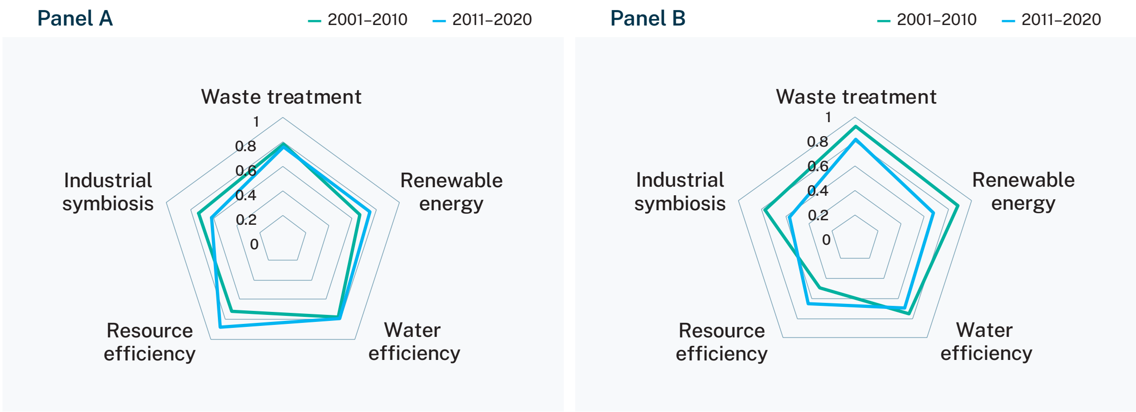
EIP technologies are widely adopted in countries with a higher complexity index (in the product space) as well in high-income countries, with upper- and lower-middle-income countries catching up (figure 2.9). The adoption of EIP technologies, especially renewable energy, waste treatment, and industrial symbiosis technologies, has increased in non-OECD countries since 2001 (figure 2.10, panel b). As a result, 21 percent of EIPs in non-OECD countries now have waste treatment measures and technologies in place; 18 percent of EIPs in these countries also have adopted renewable energy technologies.

FIGURE 2.9 Number of EIPs with technologies promoting a circular economy by their rank in the Economic Complexity Index



Note: The Economic Complexity Index (ECI) consolidates a measure of the diversity of a country's export basket and its sophistication. When countries expand their productive capacities, they can produce more diverse and less common products. The graph classifies countries with EIPs by their ECI country ranking for 2017. Countries were divided into quartiles according to the ECI (high, medium-high, medium-low, and low complexity). EIP = eco-industrial park.

FIGURE 2.10 • EIP technologies in OECD and non-OECD countries

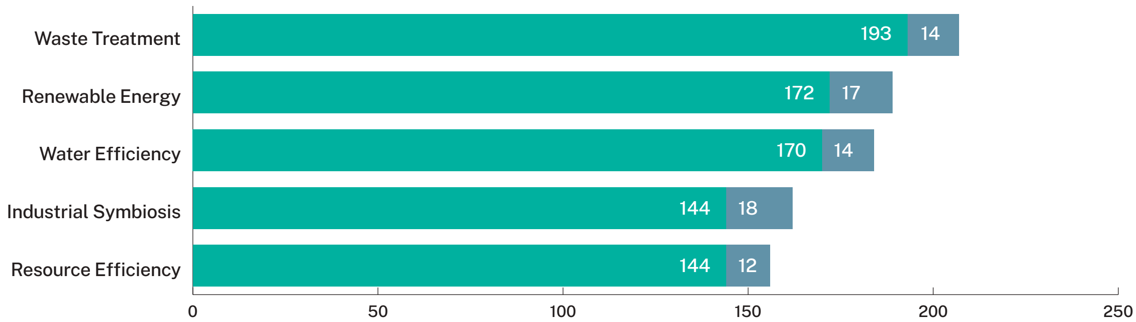


Note: EIP = eco-industrial park; OECD = Organisation for Economic Co-operation and Development. Numbers inside the graphs represent the simple probability that an EIP that starts an operation in the given range of years has the respective technology in the EIP survey year.

3. The types of park management model used may influence the adoption of certain EIP technologies.

As highlighted in figure 2.11, an on-site management entity is observed to have a significant impact on the types of EIP technologies adopted within an industrial park. The presence of on-site management and its awareness of local conditions could help accelerate the decision-making process in case of any issues. Off-site management might have reduced commitment levels and perceived barriers in decision-making.

FIGURE 2.11 • EIP technologies in industrial parks with on-and off-site park management entities



Note: Out of the total 438 surveyed EIPs, 148 had no information on the type of park management (on-site or off-site). The graph therefore does not include these EIPs while analyzing the association between the prevalence of clean technologies and on-or off-site park management.

4. A public sector presence in ownership seems to indicate a positive impact on EIP technology adoption.

More than 50 percent of the surveyed EIPs have implemented EIP technologies in all technology categories, indicating the push provided by government bodies in promoting a circular economy. Also, the limited number of PPP cases indicate that private entities have a lower business-value perception of EIP technologies — a probable action area.

5. Integration of an urban-industrial ecosystem helps extend the scope of EIPs and the sharing network for a circular economy.

Proximity to an urban agglomeration has contributed to the success of multiple special economic zones (SEZs) across the globe. It has also led to an increasing trend of linkages between industrial ecosystems within industrial parks/EIPs and service providers or firms operating outside these parks.

Industrial parks were traditionally established outside city boundaries to get land at lower costs, avoid zoning or other regulatory challenges, and manage environmental externalities more cost-effectively. Many industrial parks are becoming industrial towns or being integrated into an urban center with employees settling in or near such centers (UNIDO 2019). The growth of commercial businesses and residential areas in or adjacent industrial parks meant that such places have taken on increasingly urban economic and social characteristics — like Jubail Industrial City (Saudi Arabia), Alberta Industry Heartland (Canada) (Business Facilities 2020), and agro-zones across Africa (UNCTAD 2019). **This integration of urban-industrial ecosystems can provide important opportunities for promoting circular economy principles, known as urban-industrial symbiosis. Urban-industrial symbiosis can enable the exchange and management of waste and energy on a regional scale, making use of a wider range of material sources, infrastructure, logistics, and reuse and recycling options.** Two examples of urban-industrial ecosystems (given below) have been observed as part of the survey:

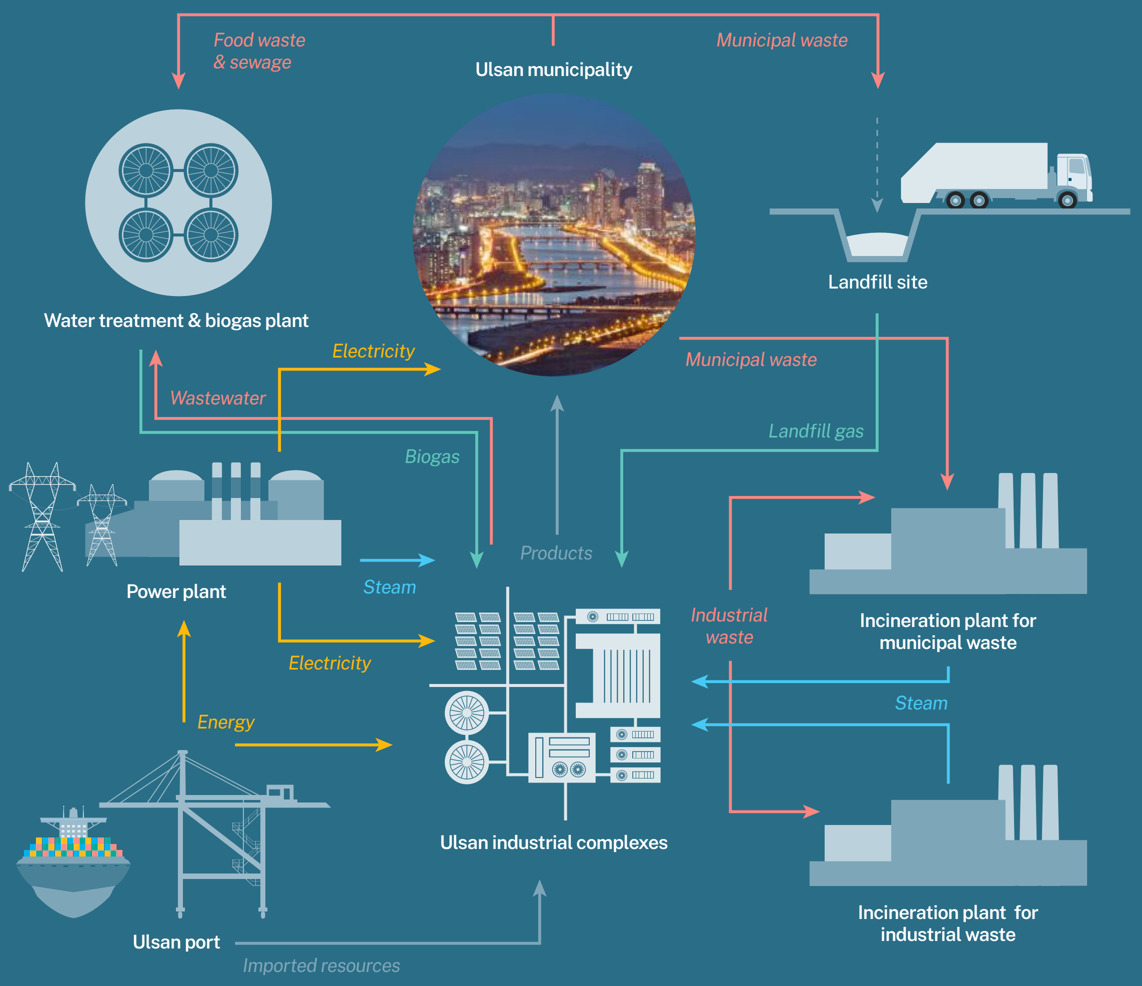
» ***Hartberg, Austria:*** The Ökopark[3] covers a 15-hectare (ha) area on the outer edge of Hartberg city — the site has been adapted to companies concerned with the production of a variety of goods and environmental services or technologies. The Ökopark utilizes the organic fraction of municipal solid waste from the city to generate electricity through a biogas plant. The biogas plant is supplemented with a solar photovoltaic system and wind turbines that supply energy for the electricity, heating, and cooling systems of the entire Ökopark, making them carbon dioxide (CO_2) neutral. Ecological waste management, wastewater treatment, and rainwater collection are also part of the integrated approach to achieve sustainable resource utilization in both the city and the Ökopark. Wastepaper from urban consumption (i.e., from newspapers, restaurants, and cinemas in Hartberg city) is utilized as raw materials for the manufacturing of cellulose insulation products, thus creating a symbiotic relationship (ECO-INNOVERA 2014).

» ***Ulsan, Republic of Korea:*** Ulsan metropolitan city and its EIP are engaged in a symbiotic relationship in which urban wastes are being used by tenant firms within the EIP in three ways:

- Part of the municipal waste is incinerated, and the energy generated is used to generate steam, which is transported to the EIP.
- The remainder of the waste is dumped in a landfill, the gas from which is transported to the EIP and used as a primary fuel for incineration in the production processes of the tenant firms.
- Food waste and sewage of the municipal region is used to generate biogas through aerobic digestion which is used as a fuel for the EIP.

Figure 2.12 shows the schematic diagram representing the three pathways (Park 2016):

FIGURE 2.12 • Urban-industrial symbiosis in Ulsan EIP, Republic of Korea



Apart from the existing relationships, waste heat generated from industrial processes, especially low-grade waste heat, can also be used for ambient heating in urban households. Through a central heating system, the waste heat generated by each company flows to the heat management center for proper heat control. This heat is then supplied to the heating systems of apartment complexes or commercial buildings in a heat exchanger. This comprises a theoretical framework for the circulation of low-, medium-, and high-pressure steam through a heat pinch for energy optimization in urban energy systems (Kim 2017).

These examples highlight the potential for integration of urban and industrial ecosystems within and around EIPs, which can scale up circular economy practices. Beyond symbiosis with urban activities, the concept can also serve rural areas favorably, leading to greater integration between industrial activities, even beyond urban settlements.

2.3 • Role of park operators in integrating circular economy principles and EIP technologies

Park operators play a vital role in developing new business strategies and making investment decisions for deploying innovative EIP technologies and integrating circular economy approaches into park operations. The synergetic effects could be substantial if these actions are planned, designed, and implemented in a systematic, concerted manner at the national, local, and park levels, as highlighted in box 2.1.

BOX 2.1

Turkey: Industrial parks transforming to EIPs

In Turkey, efforts at the national and industrial park levels spurred a number of industrial zones to develop strategies to become eco-industrial parks (EIPs). The park operators strengthened their technical and human capacities to improve environmental and energy management systems within the parks. They also improved common infrastructure and services (see also box 4.1 in chapter 4 of this report), and communicated with resident firms to identify the most suitable resource-efficient technologies and practices that were technically and financially feasible.

In the Eskisehir Organized Industrial Zone (EOIZ), for instance, the park operator implemented the following key initiatives, enabling the green transformation of the zone and integration of circular economy principles:

- **Undertaking thematic projects with regional and international development agencies** to increase the attractiveness and green branding of the zone. It participated in the ShareBOX (Secure Management Platform for Shared Process Resources) project, which was initiated under the European Union's Horizon 2020, to identify potentials on circularity for their resident firms as well as for the services they provide. As a follow-up project activity, the zone authority worked with the World Bank Group and the Ministry of Industry and Technology on the Green Organized Industrial Zones Initiative. This resulted in the translation of several diagnostics at the zone and firm levels into a strategic action plan to move toward transitioning into an EIP.
- **Establishing a "Green Cell" with full-time staff to systematize the transformation into an EIP and implement the action plan.** The unit was merged with the existing environmental management unit to report directly to the zone authority and was tasked with supporting resident firms in materializing industrial symbioses opportunities, promoting digitalization, and facilitating untapped resource efficiency opportunities.

The national government's policies, such as the adoption of the 10th and 11th National Development Plans, were crucial for accelerating these industrial-park-level efforts. The 10th Plan laid important groundwork for improving the productivity of the manufacturing sector in Turkey and the 11th Plan stimulated growth through innovation and promoting Industry 4.0. Both development plans were bolstered with clear strategies and action plans by the Ministry of Industry and Technology to make the manufacturing sector and industrial zones greener, innovative, and more productive. This clear signal from the national government spurred regional development agencies to mobilize grants that selected industrial zones can tap in order to cover feasibility studies for EIP technology investments.

While these broader policy initiatives are desirable, park operators can still integrate circular economy principles by transitioning to EIPs. The following guiding principles can help park operators increase the uptake of circular economy technologies and practices, thereby facilitating green and smart transformation of industrial park operations:

1. Establish targets and enforcing legally binding agreements.

Park operators can set and work toward ambitious targets to improve circularity of resources and minimize carbon intensity for the park and its resident firms. Setting targets can help parks and their resident firms collectively lower dependence on the use of fossil fuels and minimize GHG emissions. These targets may be included in the legally binding agreements (e.g., rental contracts), sales documents, and other kinds of agreements between the park operator and resident firms.

2. Coordinate knowledge exchange, data collection, and management; promote trust among tenants; and mediate differing interests and needs.

Park management entities are often best positioned to coordinate with the public and private stakeholders to identify and prioritize EIP opportunities that are economically and technically viable. Stakeholder engagement and the public-private dialogue process may be more complex with regard to identifying and creating industrial symbiosis opportunities as they involve two or more firms or entities and require their cooperation to identify a common interest. Given the emerging trend of urban-industrial networks promoting a circular economy, the involvement of municipal governments and their urban planning units can be a critical enabler for integrating a circular economy approach into industrial parks.

3. Optimize life-cycle costs and enhance access to collective financing for tenant firms.

Park operators should encourage private investment in common/green infrastructure investment and provide services to resident firms. Park operators need to ensure continuous and uninterrupted provision of common infrastructure and utility services to tenant firms. The infrastructure services are outsourced sometimes, and in these cases the park management ensures that services are provided to tenant firms such as electricity distribution, natural gas supply, or waste collection by the municipality.

4. Provide research and development (R&D) support and testing facilities.

R&D support and availability of testing facilities is an essential enabler for deploying commercially viable technologies. **Performance of various EIP technologies such as energy efficiency, cost savings, and GHG emissions reduction can be assessed or validated during feasibility/pilot studies. Park operators and resident firms can collectively seek financial support from national and local governments.**

5. Set up effective environmental performance monitoring systems and technologies.

To identify opportunities for EIP technologies and monitor their environmental performance after installation, park operators need to collect and monitor multiple datasets both at the firm and park levels: consolidated annual wastewater, solid waste, and annual solid waste recycled by firms and the park; annual GHG emissions; energy consumption both from the national grid and renewable sources; number of firms involved in industrial symbiosis; and number of firms with ISO 50001 (Energy Management) and ISO 14001 certification. The effective environmental impact/energy consumption monitoring systems and database systems equipped with net metering can help identify potential opportunities for new systems such as a zero-liquid discharge system (ZLD) or the need to increase the size and capacity of common effluent treatment plants, etc.

6. Certify EIPs and increase market access for resident firms.

Parkwide certification systems play a crucial role in incentivizing firms' investments in common infrastructures and increasing their access to the global circular/green product market. For example,[4] in 2013, the Mexican Association of Private Industrial Parks (AMPIP) created the "Green Industrial Park" and "Sustainable Industrial Park" programs to certify industrial parks that develop and implement actions to reduce water and energy consumption and minimize environmental pollution. To obtain this recognition, the AMPIP member industrial park operators must present evidence of actions in terms of water, energy, and emission of pollutants; comply with current regulations in these matters; and establish actions and commitments for continuous improvement in environmental care, through training, process optimization, or equipment replacement, among others. The program is aligned with the criteria of the Environmental Quality Certification granted by the Federal Attorney for Environmental Protection and has the potential to transform access to a green product market.

The role of park operators is central to implementing the circular economy concept in industrial parks in the areas of energy, water, and waste and material management. Beyond providing a strategic vision on promoting circular economy principles, they can promote the aggregated use of technologies and improve the economics of sustainability. Ensuring that the right national and local regulations are in place to promote these practices is critical. Industrial parks can capitalize on national regulations to create "centers of excellence." The following sections will highlight the main factors that enable the uptake of technologies, latest international trends in the use of these technologies, and case examples.

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Endnotes

1. It must be noted that only industrial-park-wide technologies are considered in this study. Energy efficiency measures are aligned to circular economy principles since they reduce the use of fossil fuel sources. However, energy efficiency measures are generally firm-level measures and hence have been omitted from the study.

2. The high score of EIPs in the South Asia and Middle East and North Africa regions can be attributed to the small number of EIPs in these regions: 11 and 7, respectively.

3. For more on the Ökopark Hartberg, see https://www.oekopark-gewerbepark.at/; https://p2infohouse.org/ref/24/23333.htm.

4. About Industrial Park Legislation in Mexico: https://ampip.org.mx/en/about-industrial-parks-in-mexico/.

3 Energy

3.1 • Overview

Energy is a vital input for all industrial processes and has significant influence on production capacity and costs, and thus the competitiveness of industrial parks and their tenant firms. The instability of oil prices, changes in the regulatory environment, and market demand for green products and financing due to a paradigm shift driven by global climate change are pushing firms to ramp up sustainable production processes. However, they often face challenges in finding energy supply that is low cost, reliable, and carbon neutral. Reduced access to energy and the high cost of available energy sources can potentially reduce competitiveness. For example, the power cost in many countries in Sub-Saharan Africa (except Ethiopia) is $0.20–0.50/kWh—more than double the global average ($0.10/kWh) (World Bank 2013). These high electricity rates, in turn, raise firms' production costs, which are then reflected in the prices of goods and services they provide for their customers and end users, eventually challenging the competitiveness of businesses across both the domestic and global value chains. Competitive electricity rates and reliable power supply have proven to be critical criteria in businesses' decisions regarding where to locate their operations. For example, PVH, a major textile manufacturer operating in Ethiopia's Hawassa Eco-industrial Park (EIP), cited the park's competitive electricity rate and uninterrupted and sustainable supply of utility services as critical factors in its decision to invest in the park (Mihretu and Llobet 2017).

To enhance competitiveness, industrial park management entities should operate effective energy management systems in line with internationally certified standards and actively implement innovative, economically viable practices and technologies to promote the circularity of energy resources. Two possible strategies are:

» **Greater energy efficiency and the sourcing of low-cost energy:** Park operators can strive to ensure the maximum utilization of available energy and reduce resource wastage through the effective monitoring and integration of energy-efficient technologies and practices. This implies reduced costs for energy resources, thereby contributing to enhanced competitiveness.

» **Decarbonization through increased renewable-based energy supply:** Utilizing renewable energy sources for power generation directly contributes to the core objectives of circularity, that is, resource conservation and decarbonization. Renewable energy sources are becoming increasingly cost-effective compared to fossil fuels. This has positive implications for reducing energy costs across all energy users in an industrial park. It also helps park operators attract potential investors seeking to operate climate-smart factories. Park operators and tenant firms can also tap into carbon credits, which can be traded and become a source of revenue, provided that firms' investments meet third-party verification standards.

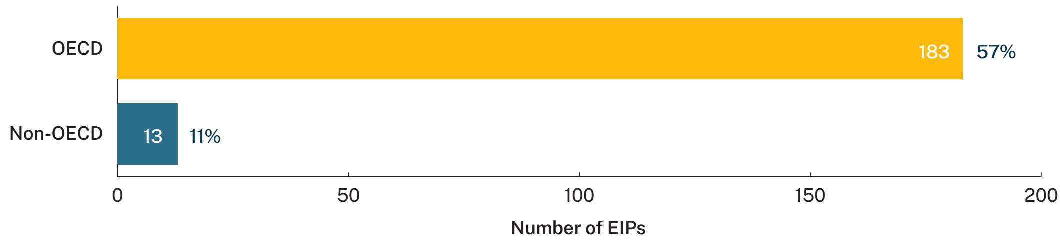
Park operators can select one of these two strategies, or both, to provide low-cost, low-carbon energy supply. For example, they can choose to adopt certain energy management business models leveraging renewable energy supply to provide clients with low-cost energy supply. Innovative practices and technologies should be explored to accelerate the adoption of each strategy or both in the context of industrial parks, as elaborated below.

3.2 • Energy management at the industrial park level

Improving energy management strategies at the industrial park level is essential for providing cleaner, low-cost, and reliable power supply to tenant firms. Energy management systems help enhance the competitiveness of industrial units by reducing energy and production costs as well as providing reliable energy. These objectives are achieved by undertaking interventions on either the demand or supply side of energy systems or a combination of interventions spanning both sides. Demand-side interventions involve energy efficiency and resource efficiency measures that reduce energy demand, thereby reducing energy costs. Supply-side interventions involve diversifying and optimizing energy sources to provide energy supply to industrial units at a lower cost and with equivalent or better reliability than conventional energy sources. The type of interventions undertaken by energy management firms generally dictate the type of business models to be adopted.

The findings from the World Bank's study (2020a) indicate that park operators are moving from a real estate business model to a service-based business model, and such a trend is observed mostly in OECD countries. A total of 196 out of the 438 (44.7 percent) EIPs have energy management systems (EnMSs) that are equivalent to ISO 50001.[1] Figure 3.1 highlights that 11 percent of 119 EIPs identified in non-OECD countries have EnMSs while 57 percent of 319 EIPs operating in OECD countries are found to have EnMSs in place. A service-based model integrates various energy management business models, provides needed infrastructure, and builds up business and service provision skills to support tenant firms with competitive energy management services that range from captive power generation to trading and distributing electricity from the national grid. The availability of energy management system certification, which provides a means of understanding the requirements of an effective system as well as measuring its effectiveness, has furthered the adoption of a service-based model across industrial parks. The following subsections elaborate on how energy management business models and certifications can help park operators enhance their competitiveness while aligning with circularity principles.

FIGURE 3.1 • EIPs with energy management systems



Note: Total number of EIPs with energy management systems = 196. OECD = OECD countries; Non OECD = Non-OECD countries.

3.2.1 • Energy management business models

In general, various business models exist for the implementation of energy efficiency and renewable energy interventions. The following three models are commonly encountered in industrial parks around the world:

» **Energy performance contracting (EPC):** A set of turnkey services (i.e., engineering design, planning, constructing, operation, and maintenance) and project financing, primarily for demand-side interventions that provide customers with a guarantee that cost savings from the project will exceed financing requirements (US EPA 2007).

» **Energy supply contracting (ESC):** A set of turnkey services and financing for interventions related to sourcing and distribution of energy (i.e., electricity, compressed air, or heat supply) to provide customers with low-cost, efficient, reliable, and clean energy supply (EU ESCO n.d.).

» **Integrated energy contracting (IEC):** This option combines EPC and ESC strategies to reduce energy demand through energy-efficiency measures and low-cost, reliable energy supply, preferably from renewable energy sources (Bleyl-Androschin 2011).

Energy service companies (ESCOs) are often involved in providing energy services under the business models mentioned above. Definitions of ESCOs and the ambit of their services vary across regions. EPC is prevalent in markets where demand-side energy efficiency is also prevalent (as in developing economies like China, India, Thailand, and developed economies such as the United States), while ESC is prevalent in European countries like France and Germany. ESCOs' operations have been instrumental in furthering the penetration of energy-efficient technologies across the commercial and residential buildings sector globally, while their presence in the industrial sector increases gradually. ESCOs in the industrial sector are common in Asian markets (with China being the dominant player) and limited in North American and European markets.[2] In the industrial sector, EPC is the most common type of energy contracting, as observed in China (International Energy Charter 2018).

The application of all three business models for energy management in industrial parks helps avoid inefficient resource and energy consumption, and provide power supply to tenant firms at a competitive price; in turn, this helps enhance resource conservation, mitigate GHG emissions, tap into new revenue streams such as obtaining carbon credits, and reduce production costs significantly. EPC focuses on improving efficiency on the demand side to reduce fuel consumption. ESC focuses on improving the efficiency of energy supply, with a similar goal. IEC, being an integration of EPC and ESC models, furthers the resource circularity and increases renewable energy use. Adoption of any of the three models in an industrial park will help tenant firms ("the end consumers") outsource the commercial and technical risks of implementing renewable energy or energy-efficiency technologies, while benefitting from the outcomes.

As noted earlier, EPC is the prevalent contracting option among ESCOs in the industrial sector. In this model, performance risks can be distributed between the beneficiary and ESCOs in one of three ways: (1) guaranteed, (2) shared, and (3) no investment (Glasmeier et al. 2013) (table 3.1). These risk-sharing mechanisms provide incentives for park operators and ESCOs to invest in projects to improve energy efficiency.

TABLE 3.1 • Three ways of allocation risk under the energy performance contracting model, across three scenarios

Energy service company (ESCO) contract	Scenario 1: Savings objectives *achieved*	Scenario 2: Savings objectives *not achieved*	Scenario 3: Savings objectives *overachieved*
Guaranteed	The industrial park takes all the savings profit but pays a share of it back to the ESCO	The ESCO pays savings profit to the industrial park	The industrial park takes all excess returns
Shared	The industrial park and ESCO share the profit	The ESCO pays savings profit to the industrial park	The industrial park and ESCO share the excess returns
No investment contribution	During the contract lifetime, the ESCO takes all savings profit	The loss rests with the ESCO	The ESCO takes all excess returns during the contract lifetime, after which the industrial park takes them

Source: Original compilation.

Regulatory and policy frameworks may be needed to boost and streamline the use of the EPC model for investments in EIPs, as done in the Republic of Korea (box 3.1).

In the EPC model, park operators can act as demand aggregators and focus on providing tenant firms energy supply/energy efficiency improvement services. The EPC model requires park operators to not only monitor energy savings performance at the park level but also to develop internal functions and capacities to negotiate, trade, balance, control, and monitor the energy supply services they provide to tenant firms. Through this approach, park operators can make sure that firms have access to reliable power that is low cost and from low-carbon energy sources. This model is most effective in countries where the energy market is liberalized at the national level. See box 3.2 for a comparison of models across two countries: Thailand and Italy.

Park operators are increasingly utilizing a mix of ESC and EPC business models to deliver packaged services to increase renewables-based energy supply and improve energy efficiency in a cost-effective manner. This is a win-win approach that has been very successful in many countries (see box 3.3 for the examples of Germany and Turkey). Other business models introduce in different ways a remuneration based on cost saving benefits to be shared between the park operators and the tenant firms.

BOX 3.1

Korea: Promoting energy performance contracting in industrial parks

In Korea, the legal basis for implementing the EPC model through energy service companies (ESCOs) was provided by amending the Energy Use Rationalization Act in 1991. The Korean government has institutionalized the ESCO's EPC contracts through the Korea Energy Agency (KEA) to streamline energy-improvement-themed investments. Under this framework, KEA provides loans to ESCOs to replace the inefficient facilities of energy consumers through a guaranteed savings model.

With this enabling environment, the EPC model was used in Korea's flagship eco-industrial park (Ulsan EIP) within a shared ESCO EPC model. Three parties were involved in the investment: the Korea Industrial Complex Corporation (KICOX), Ulsan EIP (through Ulsan Metropolitan City), and the ESCO. In the industrial park, a 6.2 kilometer steam highway was constructed to provide excess steam from a chemical company to steam users throughout a 15-year contract. Forty-eight percent of the initial investment of $66.7 million was financed by KICOX and the ESCO fund. It is expected to generate an economic benefit totaling $31.7 million per year to the three parties involved in this project from 80 tons/hour of steam sales.

Source: Park, Park, and Park 2018, 201.

BOX 3.2

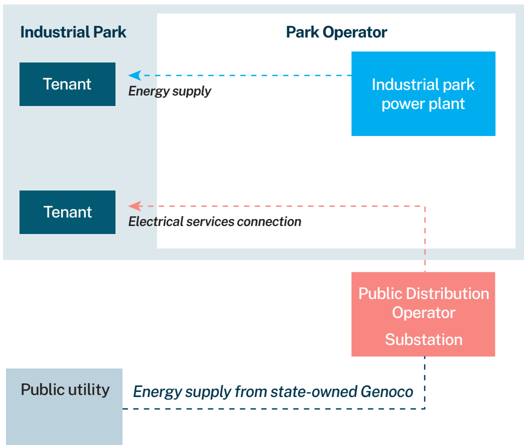
Energy supply and energy performance contracting: A comparison of two models across two nations

Energy supply contracting (ESC) model

About the example park where it was applied

The Amata City Chonburi Industrial Estate, spread over 4,330 hectares (ha) with 689 operating factories and a workforce of 203,000, is one of the largest industrial parks in **Thailand**. It is managed by the Amata Corporation Company Limited (AMATA), which is a group of companies engaged in the development of industrial estates throughout Thailand and Vietnam (AMATA 2015).

FIGURE B3.2.1
Amata Industrial Park energy supply block diagram



How the industrial park provides energy supply and services

Reliable power at 22 kilovolts (KV) is supplied for all plots by the Government of Thailand producer, the Provincial Electricity Authority (PEA).

The park also provides an optional power source: Amata B. Grimm Power Company, under the Small Power Producer Program (SPP), produces highly reliable, stable electricity for the Electricity Generating Authority of Thailand (EGAT) through its 734 megawatt (MW) plant installed inside the industrial estate (AMATA 2019). It also supplies steam, power, and related services to customers at Amata City Chonburi and another industrial park located nearby — Amata City Rayong Industrial Estate.

Private producers can generate power through renewable energy sources under the SPP. Accordingly, the plants operating under the SPP are gas-fired combined cycle cogeneration power plants equipped with heat recovery system generators.

Amata B. Grimm Power Companies are joint venture businesses between B. Grimm Power Limited and Amata Corporation PCL — the parent company of the park operator.

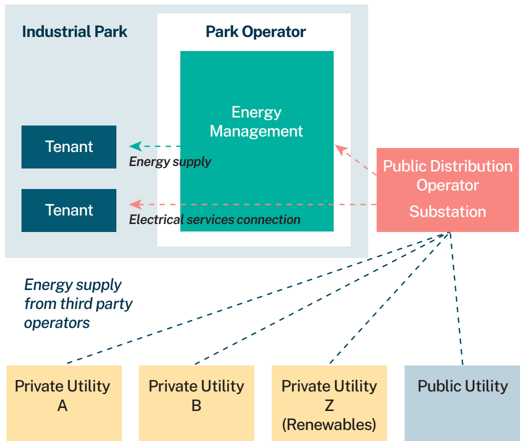
AMATA was able to optimize the costs and profits by running its own power plants (captive generation) and being more competitive than the local state-owned utility. This was possible because power distribution fees are not applicable to closed distribution areas, as depicted in figure B3.2.1.

Energy performance contracting (EPC) model

About the example park where it was applied

In **Carnia Industrial Park, Italy**, the Consortium for Industrial Development of Tolmezzo, a public economic body since 1999, plays the role of park operator and oversees land use and production, while providing industries with innovative technological systems. The park has a workforce of 2,300.

FIGURE B3.2.2
Carnia Industrial Park energy supply



How the industrial park provides energy supply and services

The park operator has signed a multiyear collaboration agreement with an ESCO (CiviESCo) to help tenant firms access electrical services at competitive prices. In particular, the agreement provides for integrated energy services through the planning, programming, design, implementation, supply, and rental to third parties of initiatives, interventions, services, and systems, for optimization and reduction of energy consumption on the demand side.

CiviESCo draws up authorization procedures and requests for access, along with handholding support to tenant firms related to financing issues for energy sourcing, energy audits, reporting and measurement of savings achieved, and implementation of energy-efficiency measures. For its energy services, CiviESCo operates on a guaranteed savings variant of the EPC model.

Such a trading scheme is possible because the liberalized market in Italy allows multiple operators to offer energy supply to the park operator and its tenant firms at competitive prices. As a result, the park operator can reduce capital expenditure in investing in captive power plants or associated infrastructure. The park operator has also designed and constructed renewable energy power plants including 13 photovoltaic plants and a hydroelectric plant to meet the needs of its tenant firms.

In collaboration with the ESCO, the park operator of Carnia Industrial Park focuses its business strategies on offering energy trading and energy management services. These services include free energy auditing services to resident firms, aggregation of demand, and negotiating directly with utilities to provide power supply to tenant firms at a price lower than the current market price.

Energy supply contracting (ESC) model	Energy performance contracting (EPC) model
Regulatory and market environment While power generation, transmission, and generation in Thailand are regulated, the Thai government has allowed private power producers in power generation from renewables under three programs: 1. **Independent power producer (IPP) program:** Build, own, and operate power plants with generating capacity above 90 MW and enter long-term power purchase agreements with EGAT. 2. **Small power producer (SPP) program:** Build, own, and operate power plants with 10–90 MW capacity range and to enter into PPAs with EGAT. 3. **Very small power producer (VSPP) program:** Private firms generating up to 10 MW of renewable energy can sell power to the Metropolitan Electricity Authority or the Provincial Electricity Authority. SPPs and VSPPs using renewable energy sources are eligible for a feed-in tariff on top of the wholesale electricity price. The electricity market in Thailand is regulated: • **Generation:** The Thai government has continuously promoted private sector investment in the generation business, through bid solicitations for power purchase from large-scale IPPs and also SPPs. • **Transmission:** EGAT is the sole operator of the electricity transmission system in Thailand. • **Distribution:** The two distribution companies are state owned. • **Supply:** The Thai electricity supply industry is based on a state-owned enhanced single-buyer scheme. EGAT is the single buyer of bulk electricity, under terms and regulations set by the Energy Regulatory Commission.	***Regulatory and market environment*** In Italy, the regulations governing energy trading are critical for enabling greater uptake of renewable energy sources and energy management services, as they can help supply energy to tenant firms at competitive rates. The electricity market is set up to match energy supply and demand, and to contribute to the needs of the overall electricity system. Trading between generators and suppliers takes place on the Italian Power Exchange (IPEX). In addition to the trading operations executed on the IPEX, electricity producers and wholesalers are free to enter into over-the-counter bilateral agreements. The energy market in Italy is liberalized: • **Generation:** There are 15 large electricity-producing companies. • **Transmission:** There are currently 11 transmission system operators. • **Distribution:** There are four main distribution system operators. • **Supply:** There are more than 200 energy supply companies active in the Italian electricity market.
What other industrial parks can learn • Captive power generation can be utilized to supply power to tenant firms at a reduced cost. The integration of intrapark power transmission and distribution infrastructure with captive power generation provides the opportunity to supply power at competitive prices as compared to the power grid. • With increased focus on renewables, even under a regulated power market, renewable power generation has been opened to private power producers.	***What other industrial parks can learn*** • ESCOs can provide energy management services and identify, implement, and monitor energy efficiency measures for tenant firms. • Available renewable energy sources can provide a competitively priced power supply option.

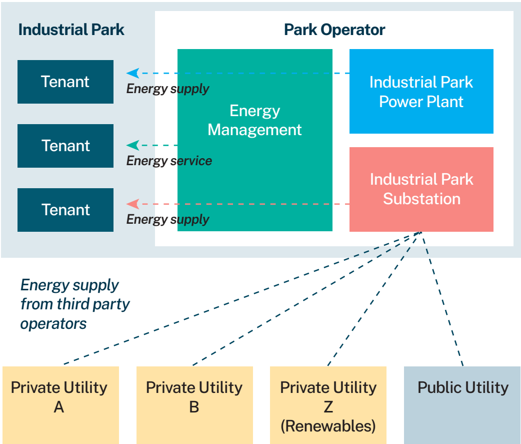
Sources: About Amata City Chonburi Industrial Estate: https://www.amata.com/en/industrial-cities/amata-thailand/industrial-cities/amata-city-chonburi/; https://www.amata.com/en/industrial-cities/amata-thailand/industrial-cities/amata-city-chonburi/key-informations/utilities/amata-utilities/amata-g-grimm-power; http://sea.poyry.com/amata-b-grimm-power-rayong-1-and-2-thailand-120-mw-combined-cycle-cogeneration-plant-projects. About Carnia Industrial Park: https://www.carniaindustrialpark.it/it/chi-siamo/; https://www.carniaindustrialpark.it/en/Construction-projects/; https://www.carniaindustrialpark.it/it/servizi-industrializzazione/Energy-Management/; https://www.civiesco.it/it/modello_di_business. For details on SPPs, IPPs, and VSPPs, see ADB (2018).

BOX 3.3

The integrated energy contracting model: A comparison of two parks across two nations

Höchst Industrial Park, Germany

FIGURE B3.3.1
Höchst Industrial Park: Energy supply block diagram



How the industrial park provides energy supply and services

In Höchst Industrial Park, Germany, the park operator offers a variety of energy services to its 90 tenant firms to optimize the use of energy and make it more competitive. Höchst has transitioned to efficient and green infrastructure and boasts sustainable energy generation, resource conservation, automated logistics, and other modern production processes.

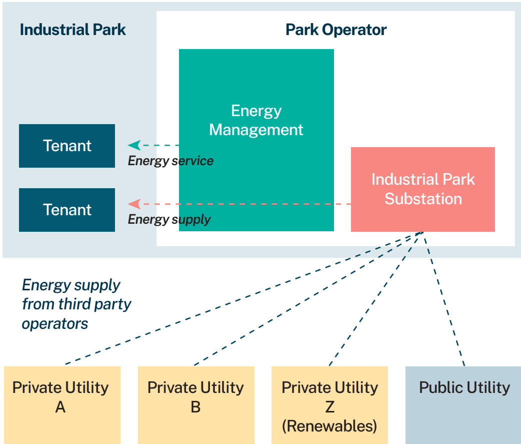
Tenant firms can optimize costs and increase utility savings through electricity supply provided by the park operator through captive generation and/or energy service company (ESCO) services. Tariffs are market based, due to the available options (captive generation and third-party supply).

Adopting the need-based supply contract, energy services are also tailored to the specific needs of the tenant firms. By providing energy management and other services to tenant firms, the park operator diversifies the stream of its revenues.

Figure B3.3.1 highlights a range of potential alternative services that a resident firm can receive, from captive power generation to bilateral contracts with utilities (including specific purchase agreements for renewable power).

Konya Organized Industrial Zone (OIZ), Turkey

FIGURE B3.3.2
Konya OIZ: Energy supply block diagram*



How the industrial park provides energy supply and services

In the Konya Organized Industrial Zone (OIZ), Turkey, the operator provides 735 gigawatts (GW) of energy supply every year to 622 active tenant firms (Konya Teknokent 2013). One of the fastest-growing industrial parks in Turkey, Konya is considered to be the future energy base of Turkey, and has significant potential to implement renewable energy sources. In 2012, 60 million square meters in the Karapinar district were declared a “specialized energy industrial zone” by the government — enabling financial assistance from the government to support development of renewable energy generation apart from facilitating investment promotion. The region is located in a prime zone for solar radiation and was able to attract solar energy investors.

Tariffs are market based. Due to the distribution license and trading of electricity from third-party suppliers, the Konya OIZ operator can optimize the costs and profits, applying competitive tariffs to tenant firms. Energy management and other services diversify the stream of revenues.

Höchst Industrial Park, Germany	Konya Organized Industrial Zone (OIZ), Turkey
Regulatory and market environment In Germany, the energy market is liberalized in all its components: • **Generation:** There are four larger electricity production companies. • **Transmission:** There are currently four transmission system operators. • **Distribution:** There are almost 900 distribution system operators registered with the Federal Network Agency in Germany. • **Supply:** There are more than 1,000 energy supply companies active in the German electricity market. Importantly, the broad set of services offered to tenant firms and the win-win strategy applied in the Höchst industrial Park are possible due to national energy regulations in Germany, which tackle the following two main issues: • Industrial park distribution systems are "closed" as electricity grids (including substations) supply customers in geographically restricted areas (generally owned by park operators). The determination of what is a closed distribution area is made by the relevant regulatory authority. Operators of closed distribution systems are exempted from some, but not all, regulatory requirements applying to distribution operators. • Construction and operation of captive generation plants are not subject to specific licensing requirements. The general provisions of the planning and building laws are applicable as are the requirements of environmental laws.	***Regulatory and market environment*** In Turkey, the main enabling energy regulation tackles the generation and distribution of electricity in organized industrial zones: generation and distribution can be carried out by public and private companies and organized industrial zones with a generation license from the Energy Market Regulatory Authority (EMRA). The energy market in Turkey is liberalized: • **Generation:** EÜAŞ (Elektrik Üretim AŞ) is the state-owned company established to carry out electricity generation activities. According to the latest figures published by EMRA in January 2019, 64.8 percent of Turkey's total installed capacity is owned by private entities. • **Transmission:** There are currently two transmission system operators (state-owned companies). • **Distribution:** Although the distribution system assets are still held by the state-owned Turkish Electricity Distribution Company (TEDAŞ), the distribution activities are now carried out by the private sector. • **Supply:** The wholesale electricity market activities are carried out by both the private entities with licenses from EMRA and the state-owned EÜAŞ.
What other industrial parks can learn • Hybrid power supply models optimize the energy costs of tenant firms based on firm-specific energy requirements as well as ensure power supply to customers in geographically restricted locations. • Diversifying power sourcing through a combination of power grid supply, third-party power supply, or captive power generation optimizes power costs. The evaluation of options should also take into consideration the provisions available in applicable regulations for the park.	***What other industrial parks can learn*** • Park operators can liaise with government agencies to explore options to exploit available renewable energy resources by attracting investment or by securing financial assistance. • Power costs can be optimized by diversifying power supply from the power grid, third-power trading companies, or from captive power generation.

Source: https://www.industriepark-hoechst.com/de/stp/menue/der-industriepark-hoechst/.

Note: *Konya OIZ has invested in captive generation to diversify the supply of electricity (solar plant: 4.5 MW, natural gas power plant: 6.5 MW). Most electricity supply is from the grid. The diagram shows only the prevalent source of electricity.

3.2.2 • Energy Management System Certification

Park operators can consider obtaining EnMS certification such as ISO 50001 to monitor and improve park-level energy efficiency performance, reduce operating costs, and meet or exceed investors' expectations. EnMS certification helps firms unlock significant cost savings through reduced energy consumption. A technical diagnostic study of the World Bank Group at the Ankara ASO-1 Organized Industrial Zone (OIZ) in Turkey suggested an initial investment cost for the certification of $190,000 (based on a 10-year investment term of 3 percent of the U.S. dollar discount rate), accounting for a payback period of 16 months.

ISO 50001 is the international standard for EnMSs, created by the International Organization for Standardization (ISO). The standard specifies the requirements for establishing, implementing, maintaining, and improving an EnMS (box 3.4).

BOX 3.4

ISO 50001

The structure of ISO 50001 is designed according to other ISO management system standards, ISO 9001 (Quality Management Systems) and ISO 14001 (Environmental Management Systems). ISO 50001 focuses on a continual improvement process to achieve objectives related to the environmental performance of an organization (enterprise, service provider, administration, etc.), as illustrated in figure B3.4.1.

FIGURE B3.4.1 • A flow diagram for implementing an EnMS following ISO 50001

Source: About EnMS and ISO50001: http://www.cleanenergyministerial.org/initiative-clean-energy-ministerial/energy-management-and-iso-50001.

Compliance with the standard can help park operators follow a systematic approach to continually improving energy performance, including energy efficiency, energy security, energy use, and consumption. The standard has been adopted by EIPs like Höchst (Germany) and Konya (Turkey) to improve energy consumption.

Implementing EnMSs in industrial parks following ISO 50001 standards can be challenging and has some cost implications, which can discourage full-fledged adoption by industrial parks. In order to implement the system, the energy baseline and energy performance indicator (EnPI) needs to be identified. This entails the additional cost of employing specialists and energy audit support. It also requires installing (and operating) automated real-time energy monitoring systems and measurement devices such as net-metering systems — and this requires up-front investment. The high cost of certification and lack of available skilled resources are additional deterrents to adoption.

National policies can help catalyze the uptake of EnMSs and transform the otherwise inefficient energy consumption of industrial parks and tenants. For example, Turkey's "Regulation Regarding the Increase of Efficiency in the Use of Energy Resources and Energy," issued in 2011, mandated industrial zones having a total of 50 or more tenant firms to establish energy management units (EMUs) to implement a parkwide EnMS (Kavak and Janssen 2016). This regulation encouraged the adoption of EnMS certification in the Ankara OIZ. Similarly, the Swedish government launched the Program for Energy Efficiency for Energy-Intensive Industry (Swedish Energy Agency 2015) as part of efforts to reduce its reliance on imported energy resources — the country sources 40 percent of its energy supply from renewables but 20 percent of its energy supply still comes from fossil fuel, the bulk of which is imported (IEA 2021). As part of the program, ISO 50001 was introduced along with a carbon tax rebate as a tool for industries to improve energy efficiencies and stay competitive against fluctuations in fuel prices. Although the statistical relationship between the presence of enabling regulations and the number of EIPs with EnMSs is yet to be proven, four countries — Sweden, Korea, Germany, and Mexico — ranked high in terms of the implementation rate of EnMSs in self-declared EIPs (93 percent) (table 3.2).

TABLE 3.2 • Results from a World Bank survey on the adoption of EnMS in EIPs

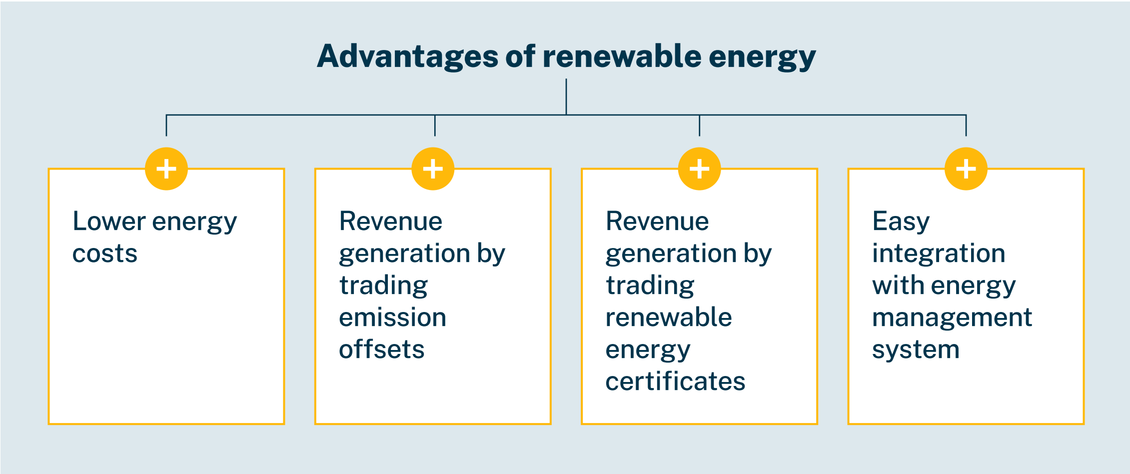
Country	Number of self-declared EIPs	Number (and share) of EIPs with EnMSs (%)
Mexico	9	8 (88%)
Sweden	6	6 (100%)
Germany	22	21 (95%)
Korea	105	95 (90%)

Source: World Bank 2020a.

In summary, through the EnMS, industrial park operators work effectively with tenant firms to identify the baseline of energy consumption and monitor and optimize the energy consumption of tenant firms at a higher-level using performance indicators. A park-level certification would help tenant firms reduce the cost of adopting ISO 50001 individually.

3.3 Renewable energy technologies

FIGURE 3.2 • Key advantages in adopting renewable energy for industrial parks



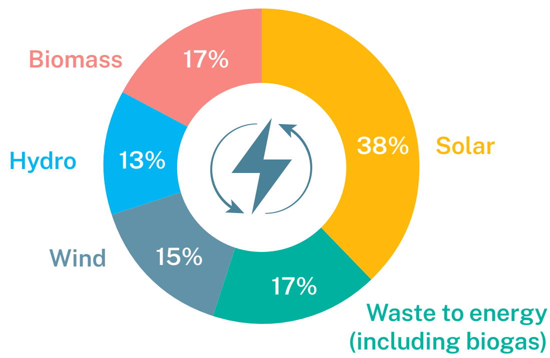
Source: Original compilation.

As discussed earlier, the adoption of low-cost renewable technologies is one of two strategies that can be adopted by park operators to enhance the competitiveness of tenant firms, by way of lower energy costs. Additionally, use of renewable energy sources can also provide revenue-generating opportunities for park operators through two routes — emissions offsets can be traded in markets with an emissions trading system[3] (as in the European Union and China), or markets can feature the option of trading renewable energy certificates[4] (as in India). Renewable power generation can also be integrated with the energy management services described in section 3.2 to enable park operators to integrate the circular economy approach and provide a holistic energy system solution to tenant firms.

There are multiple renewable energy sources for park operators to consider when seeking to decarbonize their energy production, consumption, and supply system: solar power, wind power, hydropower, waste-to-energy and biomass, geothermal, and green hydrogen.

According to the World Bank survey conducted for this report, industrial parks have increasingly installed and invested in captive renewable energy plants, especially solar PVs (figure 3.3). Thirty-five percent (120 of the surveyed industrial parks) use a renewable source of energy and 30 percent have adopted an established energy management system like ISO 50001. Specifically, 30 percent have invested in renewable-based captive generation while 7 percent

FIGURE 3.3 • **Distribution of renewable energy source in 120 self-declared EIPs**



have invested in more than one type of renewable energy solution. Nearly 72 percent of total renewable captive generation capacity in the surveyed EIPs comes from solar, biomass, and waste sources, with solar contributing to over 50 percent of this share.

The prominence of solar is primarily due to its low levelized cost of electricity (LCOE)[5] as compared to other power sources. Table 3.3 lists the expected LCOE of the 10 most commonly used technologies in the United States in 2025 (US EIA 2020).

TABLE 3.3 • LCOE comparison for new generation resources entering service in the United States, 2025 ($/MWh)

Type of technology	Capacity factor[a] (%)	Levelized capital cost[b]	Levelized fixed O&M[b]	Levelized variable O&M[b]	Levelized transmission cost[b]	Total system LCOE[c]
Dispatchable technologies[d]						
Ultra-supercritical coal	85	47.57	5.43	22.27	1.17	76.44
Combined cycle	87	8.40	1.59	26.88	1.20	38.07
Combustion turbine	30	16.17	2.65	44.33	3.47	66.62
Advanced nuclear	90	56.12	15.36	9.06	1.10	81.65
Geothermal	90	20.38	14.48	1.16	1.45	37.47
Biomass	83	39.92	17.22	36.44	1.25	94.83
Nondispatchable technologies[d]						
Onshore wind	40	29.63	7.52	0.00	2.80	39.95
Offshore wind	44	90.95	28.65	0.00	2.65	122.25
Solar PV	**29**	**26.14**	**6.00**	**0.00**	**3.59**	**35.74**
Hydroelectric	59	37.28	10.57	3.07	1.87	52.79

Source: US EIA 2020.

a. Capacity factor: Ratio of actual electrical output to the maximum possible electrical energy output over a given period. Multiple factors contribute to the capacity factor, including plant operating time, availability of energy resource, economic factors, and other regulatory factors like pollution control.

b. Levelized costs (capital, fixed and variable operation and maintenance [O&M], and transmission): Present value of cost components for installation, operation, and maintenance of power generation plants. Fixed O&M costs are incurred whether the power plant is operational due to regular maintenance, monitoring, or inspection. Variable O&M, on the other hand, is dependent on the level of operations of the power plant and includes cost of fuel, consumables, etc.

c. Total system levelized cost of electricity (LCOE): Sum of levelized cost components and total cost of power generation from a specific technology.

d. Dispatchable/non-dispatchable technologies: Dispatchable technologies can dispatch electricity to the grid on demand at the request of power grid operators according to market needs. Non-dispatchable technologies help maintain grid balance in times of fluctuating demand, which prevents extreme events like a grid collapse.

As illustrated in table 3.3, the LCOE of solar power is the lowest among the LCOEs of the 10 most used renewable and nonrenewable technologies — the low operation and maintenance (O&M) cost being a key factor contributing to overall system LCOE. This trend is supported by governments' efforts to further bring down the costs and boost subsidy-free deployment of solar energy through various incentives such as performance-based incentives (incentives paid based on the actual energy production of a solar system over a period of time).[6]

While geothermal energy, as a renewable source, has a low LCOE similar to solar, its application has been limited in locations such as Iceland, since the energy form depends on location-specific characteristics of the Earth's crust. Green hydrogen[7] is also an emissions-free fuel alternative expected to become a strong option for park operators that will enable energy storage and dispatch with future technology advancement. The following sections mainly focus on solar, wind, and biomass/waste-to-energy technologies that have been adopted in industrial parks.

3.3.1 • Solar power

Park operators can consider three types of technologies when planning to invest in captive solar energy: photovoltaic (PV), concentrating solar power (CSP), and solar heating and cooling (SHC) systems. While solar PV is the most commonly used, CSP and SHC also exhibit considerable potential in EIPs. The benefits, key challenges, and cost implications of each option are outlined below along with a basic summary of operating principles, to aid decision-making.

Photovoltaic

In industrial parks, three main configurations of solar panels can be adopted (1) ground mounted, (2) rooftop mounted, and (3) floating (World Bank Group, ESMAP, and SERIS 2018). At present technology maturity levels, ground- and rooftop-mounted solar panels are most commonly available, while commercial application of floating solar systems is underway. These solar panels can be installed in various areas in or near industrial parks, such as open spaces not earmarked for future development activities, available water bodies in the vicinity, or shadow-free areas on the roofs of tenant firms. Surfaces like parking canopies have also been utilized for the installation of solar PV systems in industrial parks. Electricity generated from these solar panels can be injected into the main power grid (i.e., on-grid) or can be used for consumption by the individual firm or group of firms instead of connecting with the power grid (i.e., off grid) (World Bank Group, ESMAP, and SERIES 2018).

With on-grid solar PV systems, any decrease in the power bills of park operators and tenants may depend on the type of metering.

- **Gross metering:** The solar PV system includes a unidirectional "gross meter" and all power generated from the system is injected into the grid. The consumer is charged with a power supply tariff for the power drawn from the grid, while a fixed feed-in-tariff (FiT) is provided as compensation for power injected into the grid.

- **Net metering:** The solar PV system includes a bidirectional "net meter" and power generated from the system is injected into the grid after captive consumption. Customer billing is based on net consumption, that is, the difference between power drawn from the grid and captive power consumption. Power drawn from the grid after captive consumption is charged at the power supply tariff, while power injected into the grid after captive consumption is compensated at the FiT level.

The relative position of FiTs against grid power tariffs has significant implications for the power bills of park operators and revenue opportunities of power distribution companies (discoms).[8] It has been observed that FiTs have been decreasing globally, in some cases to be at par with prevailing grid power tariffs (as in Vietnam) or even lower (as in India; see ET EnergyWorld [2020a]). This trend is expected to affect the revenues of discoms, thereby influencing legislation (as in the case of India[9]) and limit how many park operators choose the more economical metering mechanism, namely, net metering.

Key considerations for implementation

An assessment of technical design parameters and market conditions related to specific technology will inform implementation plans. Accordingly, the following site-specific technical design parameters need to be assessed:

- » Shadow-free area available in the proposed site (which normally includes nonoperational land like parking lots, rooftops, and water basins)
- » Annual solar irradiation for the location
- » Variations in the efficiency of solar panel options, based on available area and annual solar irradiation

The technical parameters can be used to estimate power generation potential as well as financial viability including capital expenditure (CAPEX) and operating expenditure (OPEX). Subsequently, these costs can be compared with the benefit of the power costs avoided to estimate the viability of the project.

Apart from technical parameters, market conditions like the availability of domestic distributors/ maintenance operators of solar panels, inverters, and batteries can have a considerable impact on the cost implications as well as ease of implementation.

Economics of technology

The life-cycle cost of solar PV investments, that is, LCOE, depends on the cost of both the installation technology and its operation and maintenance. The investment in a solar PV system is deemed financially viable if $LCOE_{solar}$ is lower than the average grid power tariff. Park operators planning to invest in solar PV systems need to evaluate $LCOE_{solar}$ that shows regional variations due to differences in installation and O&M cost, as well as power tariffs.[10]

Despite many variations, the LCOE of solar PV systems, relative to that of other conventional energy sources, has been decreasing across all major developing and developed economies and is expected to continue to decrease further (figure 3.4) (IRENA 2019). In India, for example, power generation costs from solar are already lower than coal-based thermal power generation. This trend will likely continue, thereby improving the viability of solar PV systems for park operators even more.

A floating photovoltaic (FPV) power plant is another emerging solar PV installed in industrial parks. Solar PVs can be installed leveraging water bodies found in or near industrial parks. They can thus generate renewable energy without using valuable land in industrial parks, and are being implemented in many parts of the world including Bangladesh (box 3.6). Advantages of FPV over land-based systems include higher energy yield, reduced evaporation, and improved water quality, among others (World Bank Group, ESMAP, and SERIS 2018). The general layout of an FPV system, as described in figure 3.5, is similar to that of a land-based PV system, other than the fact that the PV arrays and often the inverters are mounted on a floating platform. The platform, together with its anchoring and mooring system, is an integral part of any FPV installation (World Bank Group, ESMAP, and SERIS 2018, 1).

BOX 3.5

Ground-mounted solar technology in Konya Organized Industrial Zone (OIZ)

Overview

- **Location:** Konya, Turkey
- **Number of companies (active):** 622 (773 land parcels, 762 allocated parcels)
- **Sector distribution:** Machine and equipment production, motorized land vehicles, trailer production, rubber production, plastic goods, and food product production
- **Number of employees:** 42,000
- **Area:** 2,283 hectares (total)—73 percent area is for industrial use (1,661 hectares), 0.1 percent for trade-related use (2.8 hectares), 1.2 percent for technical infrastructure development (27 hectares), and the remaining 25.7 percent area for other allocated uses
- **Year of establishment:** July 1976 (development plan approval date)
- **Economic significance:** Konya OIZ hosts most of the small and medium enterprises seen in such zones in Turkey, and ranks fifth for number of firms in industrial production.

Background

Konya OIZ, established in 1976, hosts 622 companies—4 percent of which are registered in Turkey. The park comprises 773 land parcels, out of which 762 have been allocated and 622 firms are in active production. The largest of the 11 OIZs operating in Konya, a heavily industrialized region, it is pivotal in the economy of the region. The zone is under development, with construction complete for nearly 94.4 percent of the water, gas, and power distribution network. The zone has a distribution license and also has an energy management unit set up. Annual natural gas consumption in 2019 was 66,015,039 cubic meters (m^3), while power consumption was 661.71 gigawatt-hours (GWh).

Circular economy solution and technologies

Ground-mounted solar farms with a total capacity of 4.5 megawatts were built on three pieces of nonoperational land within the park (figure B3.5.1). The total size of these solar farms is approximately 65,000 m^2. In this case, the energy generated in the industrial park is distributed to tenant firms.

Economics

- **CAPEX:** \$4.5 million (for a total area of 65,000 m^2 with annual power generation of 6.01 GWh)
- **Annual OPEX:** \$0.034 million (considering 0.75 percent of CAPEX as annual OPEX)

Enablers

Turkey has several regulations enabling the penetration of renewable energy like the Renewable Energy Law, which introduced feed-in-tariffs for renewable power generation. Also, policies establishing targets for renewables' share in the power mix of the nation can be found in the Strategic Plan released by the Ministry of Energy and Natural Resources. Following liberalization of the electricity market in 2001, electricity generation, distribution, and supply were opened up to private entities—and this has stimulated private sector investment. Renewables in Turkey have been receiving financing support from entities like the European Bank for Reconstruction and Development (under its TurSEFF facility, the bank has pledged $245 million for renewable energy and energy efficiency initiatives [EBRD 2011]) and the Industrial Development Bank of Turkey (TSKB).

Results

- **Utility cost savings:** Considering the average tariff in 2019 ($0.087/kWh) and total power generation potential, annual power cost savings for the park are approximately $804,000.

- **Annual greenhouse gas reduction:** 4,420 tCO_2e (considering only grid electricity is replaced and the grid emission factor of Turkey is 478 tons/GWh).

FIGURE B3.5.1 • **A ground-mounted solar farm in Konya OIZ**

Source: Konya OIZ authority.

Lessons learned for park operators

As exhibited in the case study, park operators can utilize the available free area to provide renewable-based captive power generation. This can help park operators utilize facilities like time-of-day tariffs to reduce energy costs (that is, firms utilize grid power when the tariff is low and utilize power generated from solar system when the tariff is high). Park operators, however, need to understand the national regulatory landscape before implementing such a system, as in some nonliberalized markets permission to generate and distribute power in industrial parks may be restricted.

Applicability in developing countries

- **Possibility:** High

- **Strengths:** Technology relatively well disbursed and client apprehensions related to implementation limited

- **Weakness:** Parkwide infrastructure development required to attain economies of scale

- **Required enablers:** Policy enablers related to tariff structuring of renewable sources

Sources: Konya Chamber of Commerce (2018) and OSBÜK's (OIZ's managing authority) database: https://portal.osbuk.org/OSBBilgiPortal/; details of land parcels: http://www.investinkonya.gov.tr/en/yatirim.asp?SayfaID=11; solutions, technologies, and economics: information from Konya OIZ authorities; and overview of power regulation in Turkey: https://uk.practicallaw.thomsonreuters.com/0-523-5654?transitionType=Default&contextData=(sc.Default)&firstPage=true.

BOX 3.6

Floating solar technology in the Bangabandhu Sheikh Mujibur Shilpa Nagar (BSMSN) Economic Zone

Overview

- **Location:** Mirsarai, Sitakund, Sonagazi, Chattogram, and Feni in Bangladesh
- **Number of companies:** 131 entities allocated 6,121 acres with a proposed investment of around $19.5 billion, which includes foreign investment initiatives of 12 major entities contributing approximately $8 billion (BEZA 2020).
- **Sector distribution:** Garments and garment-supporting industries, agroproducts and agroprocessing products, integrated textiles, leather and leather products, shipbuilding, motorbike assembly, food and beverage, paint and chemical, paper and products, plastics, light engineering (including auto parts and bicycles), and pharmaceutical products
- **Number of employees:** Zone under construction
- **Area:** 12,140 hectares (total), 6,475 hectares (under development).
- **Year of establishment:** In development
- **Economic significance:** BSMSN is expected to create employment opportunities for 1.5 million people in the next 15 years and ensure $40 billion in exports (currently the value of exports of the entire country is $44.44 billion).

Background

BSMSN is the first planned world-class business and industrial city in Bangladesh. Out of a total 30,000 acres, 1,300 acres of developed land are available for allotment, while 6,000 acres have already been allotted to investors. So far, local and international organizations have pledged to invest over $17.5 billion in the project, while the Bangladesh Economic Zone Authority (BEZA) has approved investments of around $12.7 billion.

Motivation and challenges

Bangladesh has made rapid social and economic progress in recent decades, leveraging abundant labor, low energy costs, and preferential trade practices due to the country's status as one of the least-developed countries. The growth rate in gross domestic product reached over 8 percent in 2019. However, the growth rate has stagnated due to multiple factors, including increase in labor costs and natural gas prices.[11] Stagnant prices and demand in end markets (such as the EU and the US markets) pushed BEZA and Bangladeshi industries to take transformative actions to restore competitiveness. In response, BEZA developed a vision of establishing 100 economic zones, developing state-of-the art green and resilient economic zones, and developing BSMSN as an example for sustainable, resilient, and environmentally sound industrial development in Bangladesh.

Circular economy solution and technologies

In partnership with the World Bank, BEZA, the management entity of the BSMSN, is piloting an innovative circular economy solution by optimizing the nonoperational areas of BSMSN for solar power generation (through ground-mounted, rooftop, and floating solar PV). Potential rooftop/ground-mounted solar capacity is 80 megawatt peak (MWp) and floating solar is 10 MWp. The total available rooftop surface for solar PVs is around 1.4 km^2. BEZA is also tapping into underutilized water basin areas in and near the BSMSN to install a floating solar PV, as the proximity of the zone to the sea offers additional space to adopt floating solar. The total size of the useable water basin areas is approximately 0.1 km^2.

Floating solar PV economics and financing mechanisms

Economics (estimated)

- CAPEX: $10 million
- Annual OPEX: Approximately $10,000 per MW of solar power generation capacity, which translates to $1 million for the entire floating solar system

Financing mechanisms

- Public-private partnership agreements between BEZA and a qualified solar PV developer to design, build, and operate the PV plants
- Power generated from the floating solar PV system will be sold to tenant firms (tariff will be decided based on more detailed feasibility assessments). In the initial years, when the occupancy rate is low, BEZA will be able to generate revenue by selling power generated from solar PVs to distribution companies.

Enablers

There is a policy-level push to promote renewables in economic zones and industrial parks—Sustainable and Renewable Energy Development Authority (SREDA) and BEZA have teamed up to provide technical support to increase the uptake of renewable energy and energy efficiency measures (UNB 2020). Bangladesh has also been leveraging financial and technical support from multilaterals in expanding renewable energy uptake. The World Bank will support the Government of Bangladesh in adding about 310 MW of renewable energy generation capacity through a $185 million financing agreement (World Bank 2019). Renewable energy is also a key area of green financing provided by Bangladeshi financial institutions: a total of $65 million has been disbursed through green finance products in 2016 (Hossain 2018). The apex bank of Bangladesh, Bangladesh Bank, also has a dedicated financing instrument for increasing renewable energy consumption, "Renewable Energy and Environment Friendly Financeable Sectors," which allocates $24 million for renewables (Hossain 2018).

FIGURE B3.6.1 • Geographical location of BSMSN in Bangladesh

Source: Google Earth.

Expected results

The floating solar PVs are expected to help replace 180 gigawatt-hours of fossil-fuel-based power generated annually with renewables and avoid approximately 80,000 tons of carbon dioxide (tCO_2) emissions.

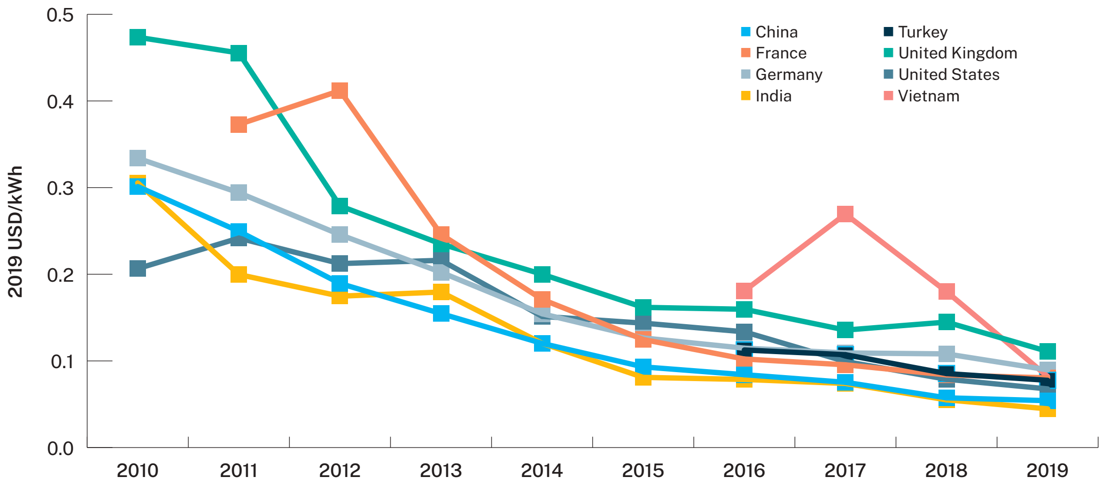
Lessons learned for park operators

Park operators, especially in developing countries, can collaborate with national government agencies to leverage multilateral funding and technical assistance for prefeasibility and feasibility assessments, introduce renewables, and improve resource circularity in industrial parks. Also, park operators can utilize vacant water bodies located in the vicinity to supplement power generation efforts but need to consider the types of natural hazards affecting the water areas and the operation of solar PVs.

Applicability in developing countries

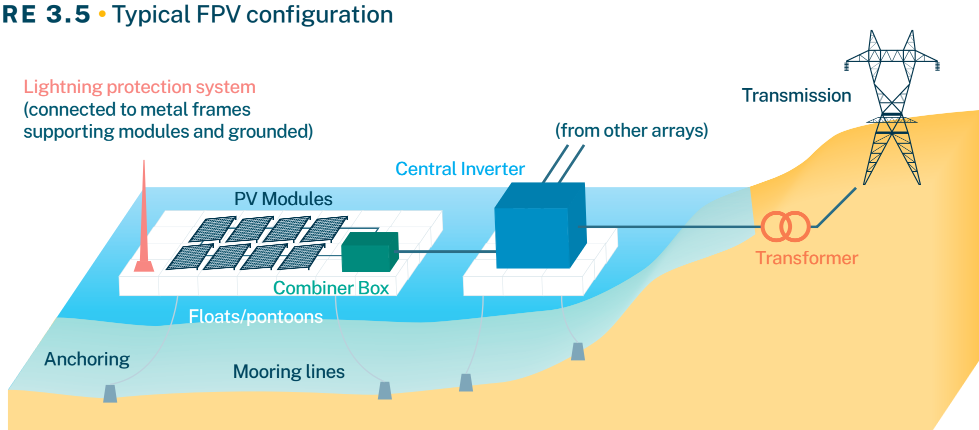
- **Medium**
- **Strengths:** Considering pressure in land utilization due to high population density in developing countries, water body areas can be effectively utilized; reduced capital costs in future help improve viability due to increased efficiency of floating solar panels over ground/rooftop solar.
- **Weaknesses:** Only applicable for parks that operate in the proximity of water bodies. Other local climate characteristics may require additional measures and improved technical designs, increasing installation costs.
- **Required enablers:**
  - *Financial incentives required to bring down costs at par with ground-mounted/rooftop solar.*
  - *Government/ multilateral financial institutions supporting demonstration projects to catalyze business cases and stimulate the market.*

FIGURE 3.4 • Weighted-average LCOE of newly commissioned utility-scale solar PV projects by country, 2010-2019



Source: Original compilation based on data from IRENA (2019).

FIGURE 3.5 • Typical FPV configuration



Source: World Bank Group, ESMAP, and SERIS 2018.

Concentrating solar power

Park operators can also consider deploying concentrating solar power (CSP) technology — a technology that uses mirrors to concentrate sunlight onto a receiver (equivalent to a boiler) that heats a high-temperature fluid, which is used to produce steam or spin a turbine or power an engine that drives a generator. In the context of industries, CSP can find use in generating electricity and in multiple processes like water desalination, enhanced oil recovery, food processing, chemical production, and mineral processing.[12]

Despite its potential, CSP is not a standard solution adopted by the surveyed industrial parks because of its high costs. CSP projects are coupled with thermal energy storage in order to raise capacity factors, contribute to lower LCOE, and provide greater flexibility of dispatch over the day. But the installation costs for such CSPs, with storage, are typically 4.5 times more than the installation costs of utility-scale solar PV and range from $3,704/

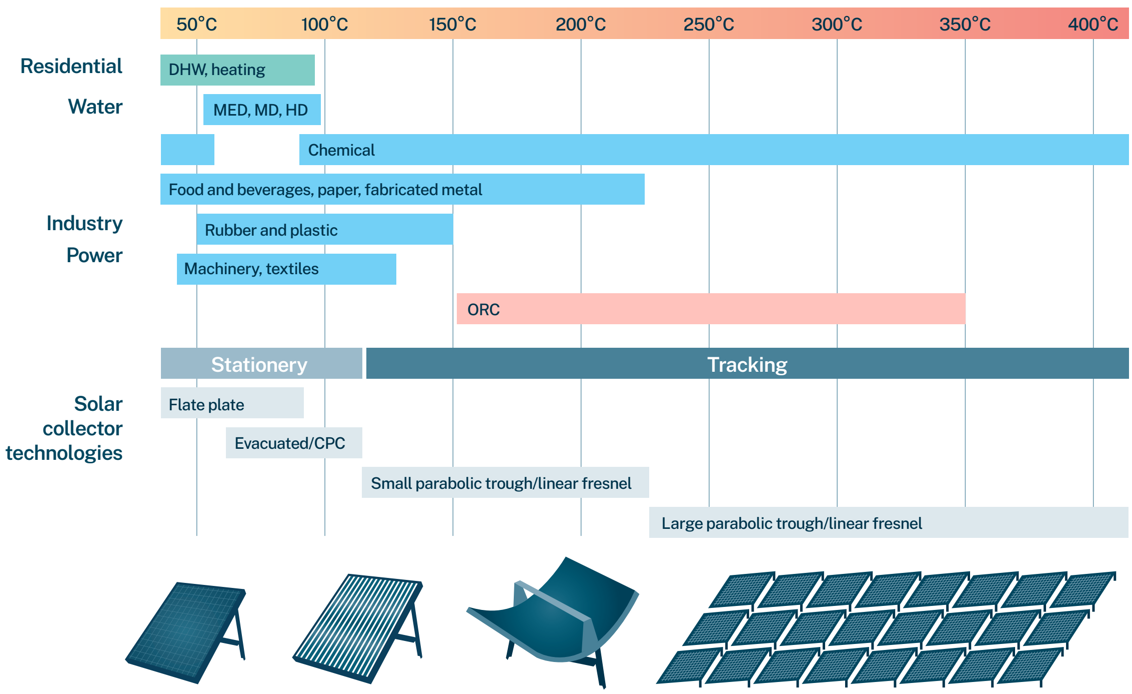
kilowatt (kW) to $8,645/kW, depending on the technology implemented (IRENA 2020a). The O&M costs typically range between $0.02/kilowatt-hour (kWh) and $0.04/kWh. The O&M costs in absolute terms are also high compared to solar PV and many onshore wind farms per kWh (IRENA 2020a). Even considering the lower limit of installation cost, CSPs have 30 percent higher LCOE than solar PV panels. In case thermal energy storage is not considered, the LCOE of a CSP will further increase.

As CSP costs continue to decline, the benefit of thermal energy storage can be utilized to meet the thermal heating requirements of industries in the future. While the World Bank survey has not identified industrial park cases with CSP, the technology is expected to mature — as exemplified by a 36 percent decline in capital costs between 2010 and 2019 (IRENA 2020a) and can be considered as a prominent candidate for application in EIPs in the future.

Solar heating and cooling

Park operators can further consider adopting solar heating and cooling (SHC) technology — a type of renewable heating and cooling technology used to generate thermal energy from different renewable sources, such as solar, biomass, and geothermal. SHC technologies utilize thermal energy from the sun to provide hot water, space heating, or cooling requirements for industrial consumers. Several solar heating technologies are available commercially, like transpired solar air collectors, flat-plate solar collectors, evacuated tube solar collectors, CSP, and a hybrid photovoltaic-thermal (PV-T) system (US EPA 2017). Figure 3.5 lists the output temperature of various types of solar heating technology variants.

FIGURE 3.6 • Solar water heating collector technologies vs. process temperatures for different industries



Source: Fraunhofer Institute for Solar Energy Systems ISE.

Depending on the steam and water temperature required for their operations, industrial parks and tenant firms operating in a region with significant solar radiation can adopt solar water heating technology. Park operators and tenant firms need to conduct technical and financial feasibility assessments based on the evaluation of the maximum actual heating/cooling load, which is determined by the following factors:

» **Areas required for heating/cooling:** The cooling/heating load of a building includes external load (heat from surroundings transferred through walls, the roof, floors, windows, doors, etc.) and internal load (heat generated by building occupants, operating equipment, lights, etc.) (IIT Kharagpur 2008). The goal of introducing a heating/cooling system is to ensure that an adequate amount of heat injection or rejection can negate any change in the external or internal load, and required temperature levels are maintained within the conditioned space.

» **Type of application:** In the context of EIPs, comfort and commercial applications[13] of the SHC system can be adopted — for administrative buildings, or directly for specific production processes or material storage, as applicable.

» **Required temperature level in conditioned space:** While the type of application decides the temperature range, site-specific assessments of conditioning requirements inform the heating/cooling requirements, thereby defining the appropriate size and type of system.

The costs of implementing SHC technologies vary significantly by technology. For example, a transpired solar air collector, which consists of a dark-colored, perforated façade installed on a building's south-facing wall, (US DOE 1998) costs \$110–\$130 per square meter (m^2) of installed wall in an existing building and \$50–\$80/m^2 for new buildings; a concentrating solar heating system costs \$700–\$800/m^2; and a hybrid PV-T system costs \$105/m^2 (Riggs et al. 2017). The costs of flat-plate (FPC) and evacuated tube (ETC) solar collectors, the solar applications used most for water heating, are approximately \$3–\$4/liter per day (Nájera-Trejo, Martin-Dominguez, and Escobedo 2016), with ETC prices around 25–30 percent higher than FPC prices.

In summary, park operators and developers planning to design, build, and operate different solar power systems need to take into consideration specific operational challenges and requirements when they preassess potential investment opportunities:

» **Solar PV systems**
- ***Site restrictions:*** Solar PV systems require specific site characteristics. For instance, solar PV panels cannot be installed on rooftops or plots that are concurrently used for any other facilities or equipment or have high structures around. Park operators need to consider plans for site changes and facility expansion when they plan and design solar panels so that they can maximize the solar potential. Park operators need to also negotiate with investors to realize rooftop solar PV installation.

- ***Fluctuation in solar-based power supply:*** Weather-related variation can lead to the fluctuation of grid solar PV system outputs, which in turn cause voltage instability, frequency discrepancies in the power grid, and in such cases, additional measures to stabilize grid are required (Olowu et al. 2018). Grid stabilization technologies are not yet mature, and as a result, power distribution companies often restrict injection of solar power into the power grid to maintain grid stability. Therefore, park operators may face restrictions from power distribution companies on the amount of solar power that can be injected to the grid. Park operators planning for captive renewable consumption should also consider having an emergency power supply available and/or battery storage system to mitigate any risks arising from power supply fluctuations.

» **Concentrating solar power**
  - ***Challenges of conducting periodic O&M:*** Owing to the complexity of installing CSP systems and requirements for specialist intervention, installations are few to date. This, in turn, affects the availability of specialists for O&M.

» **Solar heating and cooling (SHC)**
  - ***An improperly assessed SHC system can lead to higher operational costs:*** Without assessments, the SHC system may be oversized or undersized, or improper equipment and accessories may be selected (notably, ducting/piping). Oversizing is the most common problem with the SHC system design and leads to higher operational costs and unused capacity.

  - ***Lack of suitable design guidelines and tools:*** Technically sound integration and optimization of solar process heating into existing and newly built industrial plants is a key requirement for proliferation of the technology (IEA-ESTAP and IRENA 2015). Park operators have limited access to design guidelines and established tools that can support SHC design and development processes. Lack of awareness of the technology also hinders the implementation of industrial solar thermal systems.

Key enablers

A number of factors can help park operators overcome the operational challenges mentioned above and increase adoption of the solar power systems in industrial parks. These include technological advancements, characteristics of the technology, and a conducive regulatory and policy environment:

» **Reduced cost of operation:** Solar PV systems have lower O&M requirements and lower costs of operations, which help increase the adoption of the technology. Park operators can further reduce installation costs by maximizing underutilized nonoperational lands within industrial parks, such as constructed lakes or retention ponds, as illustrated in the Bangladesh case study (box 3.6).

» **Technology advancement in solar panels and battery storage:** Panel efficiency has improved,[14] and at the same time, the costs of components continue to fall due to product innovation and economies of scale (IRENA 2020a). Prices of battery storage are also expected to come down significantly[15] through sustained policy support (Cole and Frazier 2019). Increased panel efficiency, competitive battery storage capacity and prices, and the lowered LCOE can, in turn, help increase investment cost savings and stimulate private investment in and adoption of solar PVs in industrial parks.

» **Improving capacity factors for a CSP system:** The enhanced application of thermal storage will help bring down the LCOE of the technology and promote greater flexibility in dispatch over the day (IRENA 2020a) .

» **Financing or preferential loan programs:** Solar power projects are often subsidized,[16] and this trend is likely to continue until the solar power market becomes more mature. Subsidies are expected to reduce over time as returns from solar power investment improve; however, they will still be helpful for improving investment returns for park operators, especially in economies with low penetration of relevant solar power technologies. For example, in Korea, the Ministry of Trade, Industry, and Energy established a budget of approximately $84.8 million[17] to provide firms with preferential loans for the installation of solar panels in industrial parks, including rooftop solar PV (MOTIE 2020). As of 2019, more than 1,600 companies have received the loans.

» **Predictable policies and regulations to increase uptake of renewables (including solar):** The renewable portfolio standards (RPSs) implemented in multiple countries/regions have been instrumental in creating demand for renewable power (US EIA 2019).[18] RPSs mandate power supply companies to produce a specified fraction of their electricity from renewable energy sources. This creates an opportunity for park operators to utilize unused spaces within the park to generate solar power which can be sold to power consumers through a power purchase agreement (PPA) or market-based mechanisms like trading power as a commodity through specified exchanges.

» **Incentives and market-based mechanisms:** Market-based mechanisms such as power exchanges — a platform that enables electricity trading — can also help accelerate the adoption of renewable energy technologies including solar power technologies. Power exchanges help power producers generate revenue by selling excess power and buyers to find the best price in the market. For example, the Indian Energy Exchange (IEX), a government-owned electronic system-based power trading exchange, has recently launched the Green Term-Ahead Market (GTAM) platform which provides avenues to renewable energy generators for sale of power through which buyers can meet their Renewable Purchase Obligations mandated by the central electricity authority (Garg 2020). Amplus Solar, a leading owner and operator of rooftop solar power projects distributed to commercial and industrial consumers in India, has utilized the GTAM platform to sell excess power generated from renewables majorly generated in industrial premises to power supply companies (ET EnergyWorld 2020c).

» **Peer-to-peer (P2P) electricity trading is an upcoming innovative business model**, based on an interconnected platform, that serves as an online marketplace where consumers and producers “meet” to trade electricity directly, without the need for an intermediary like an exchange. The concept is majorly in pilot implementation stage with examples in the United States, United Kingdom, Germany, the Netherlands, Colombia, and Bangladesh (IRENA 2020b). The examples of implementation of P2P power trading are currently limited to residential and commercial consumers only. However, the concept can be scaled up to within individual consumers in an industrial cluster or within tenant firms of an industrial park (Yan et al. 2017, 1–5).

3.3.2 • Wind Power

Wind power is another valid alternative to solar power, especially in industrial parks where solar radiation is less prominent but substantially high wind speeds are available. Energy from wind is utilized to turn propeller-like blades of the turbine around a rotor, which spins a generator, generating electricity. Wind power can be generated from on-shore installations (which utilize wind blowing from sea to land) or off-shore installations (which utilize wind blowing from land to sea). In the context of industrial parks, location, that is, proximity to sea, is a key determinant for considering on-shore or off-shore variants.

Industrial parks in coastal locations can potentially utilize new "floating wind" technologies that provide access to higher-speed and more consistent wind resources than fixed-bottom off-shore technologies. However, due to high capital costs, the technology is at the precommercial stage.

Key considerations for implementation

Assessing a site's potential for wind power generation will help determine cost as well as the optimum choice of technology. Two technical design factors are critical:

a. Historical data on wind density over two or more years, indicating adequate wind flow above cut-in and below cut-out speed[19] of a wind turbine; and

b. Availability of large nonoperational areas (in case of a wind farm, to limit interfering disturbance among the turbines) or proximity to large water basins/sea.

Apart from the technical factors, park operators need to assess the local presence of skilled maintenance professionals to ensure seamless operations as well as facilitate estimation of OPEX.

Economics of technology

In 2019, LCOE for onshore wind came down to as low as \$0.046/kWh and \$0.049/kWh in China and India, respectively.[20] The declining LCOE for wind power, as well as a policy push for decarbonization, are stimulating industrial parks to actively adopt renewable energy sources, including wind energy (box 3.7).

Park operators can also promote wind energy and tenant firms' use of renewables overall by developing suitable contract/sales policies at the park level. Rademakers Industrial Park in Belgium exemplifies how park operators can encourage and guide tenant firms to use more renewable-based energy sources (box 3.8).

BOX 3.7

Wind power technology in Evolis Business Park (Belgium)

Overview

- **Location:** Kortrijk in Flanders region of Belgium
- **Number of companies:** 15
- **Sector distribution:** Construction materials, IT solutions, parasol system, lighting system, textile and garment, equipment, electronics, and machinery manufacturing
- **Area:** 25 hectares
- **Year of establishment:** 2009

Background

The Evolis Business Park is located in the Kortrijk region, one of the most dynamic regions in Belgium. The business park includes three smaller zones and an ecological cycling and walking circuit that helps the park reduce ecological impacts and be integrated into the rest of the urban fabric in a sustainable manner. The park operator, Leiedal (inter-local association for regional development in South West Flanders), attracts innovative companies that create a high added value by ensuring the park's sustainable development.

Motivation and enabling environment

In 2013, the federal government introduced a long-term vision to reduce greenhouse gas (GHG) emissions by 80–95 percent by 2050 compared to 1990 (climat.be 2019). In line with this vision, 13 municipalities and cities of South West Flanders agreed to promote a local sustainable energy and climate policy, aiming to reduce CO_2 emissions by 20 percent by 2020. Local governments identified zero-carbon energy systems as key strategies to meet these agreements, which stimulated the investments in wind-energy-based power generation within the park.

Circular economy solution and technologies

As part of the solution, four wind power turbines of 2 MW installed capacity were constructed on 5,821 m^2 of land within the park, providing power for both tenant firms and 5,900 households annually.

Economics

CAPEX: $11.86 million (€13.53 million)

OPEX: $87,700 (€0.1 million)

Results

The park reduces 10,311 tons of CO_2 emissions annually.

Applicability in developing countries: Medium

Strengths: Source of renewable energy contributing to self-sufficiency in energy requirement

Weaknesses: Depends on availability of wind speed; high installation costs

Required enablers: Stimulating public-private partnership through attractive investment options

Sources: About Evolis Business Park: http://www2.evolisbusinesspark.be/en/; about wind power infrastructure: http://www2.evolisbusinesspark.be/nl/sites/default/files/media/factfile_turbine_enercon_e82.pdf.

Note: The CAPEX is converted to US dollars ($) at the 2020 annual average exchange rate of $1 = €0.877, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.

BOX 3.8

Renewable energy targets and legal agreements in Rademakers Industrial Park (Belgium)

Overview of actions taken

The West Flemish Intermunicipal Service Association, which provides support for municipal governments in industrial park development (including of Rademakers Industrial Park) and management services, requires resident companies and potential investors to provide information that proves that their electricity consumption is carbon neutral. This requirement is inserted as part of residency contract / sales conditions agreements between the park operator and resident companies. Companies can choose one or more options to meet the carbon dioxide (CO_2) neutrality requirements, including:

- Agree to enter into a power supply contract with their electricity suppliers or generate from captive renewable energy sources and sign a power contract with their electricity suppliers for the remaining supply required.
- Offset CO_2 emissions from the consumption of nonrenewable energy sources by purchasing tradable emission credits based on the amount of electricity consumed.

The ministerial decree (October 1, 2007) and the Flemish Government Decree (May 16, 2007/May 24, 2013) elaborated CO_2 neutrality requirements with implications for the design and management of new and existing industrial parks. The concept of CO_2 neutrality was integrated in the subsidy decree by the Flemish government to design and manage new industrial parks or revitalize existing ones.

Outcome of the initiative

Following this requirement, 26 resident companies sourced their electricity entirely from renewable energy sources. The Belgian government's regulatory framework motivated industrial park operators to set ambitious carbon intensity targets for the park and resident firms as well.

Lessons learned for park operators

Firms are still underinvesting in renewables due to financial viability of the investments and operational risks. The renewable energy targets and legal agreements adopted in Rademakers Industrial Park illustrates that, to scale up renewables, park operators can take the following two approaches: 1) making binding contractual agreements with tenant firms to integrate more renewables in their energy use; and 2) providing services to tenant firms to help them develop cost-effective energy management strategies and lower the perceived risks. Park operators can also work with local/national governments to set mandatory renewable power purchase requirements for tenant firms and devise financial support mechanism such as tax incentives.

Operational challenges

Park operators need to address the following operational challenges when considering the deployment of wind power generation systems on site.

- **Wind power potential varies significantly based on location:** In the context of industrial parks, wind power may not be a feasible option in every geographical location, since it depends on wind speed. In case wind power is viable only at a distant location, the cost of transmission lines would push up capital costs.

- **End-of-life management of wind turbine blades:** While 90 percent of a turbine's parts can be recycled or sold, turbine blades are the opposite. Made of a tough but pliable mix of resin and fiberglass, there are limited options available for the disposal, reuse, or recycling of wind turbine blades. It is estimated that the United States alone will have 720,000 tons of blade material to dispose of in the next 20 years (Stella 2019).

- **Noise pollution caused by wind power generation:** This problem has been identified by the World Health Organization (WHO 2018) as one of the top environmental hazards to both physical and mental health and well-being in the European region, and resulted in the release of Environmental Noise Guidelines for the region in 2018.

- **Variable nature of the power generated:** Like solar, wind availability depends on weather conditions, seasonal changes, and location. Hence, the issues of grid stability encountered with solar power also apply to wind power.

- **High O&M costs:** Even as they decline amid intense market competition, the costs of O&M account for nearly 30 percent of wind power's LCOE (IRENA 2020a).

Key enablers

Implementation of wind power solutions has typically been enabled by financial incentives and regulatory push as given below:

- **Financial support in the form of subsidies:** After solar power, onshore wind was the second-highest receiver of government subsidies in energy globally in 2017, with subsidies totally $31.6 billion (Taylor 2020). The receipt of subsidies has helped reduce financial barriers and increased the penetration of the technology.

- **Renewable portfolio standards:** As discussed in the context of solar power, RPSs have had a significant impact on the uptake of renewable technologies, including wind power. Since RPSs do not differentiate between renewable sources, project proponents tend to favor technologies that exhibit significant technical potential.

3.3.3 • Biomass and waste-to-energy

Organic waste/biomass thermal treatment can be designed as integrated services between municipalities and industrial zones. The will help generate renewable-based power at a competitive price; minimize the growing volume of waste generated from industrial parks and local communities by using the waste as feedstock for energy (heat and a power) generation; and reduce landfill requirements. However, by-products generated from thermal waste-to-energy systems can pose serious health, environmental, and climate-related risks, if not treated appropriately. In light of these potential issues, an effective waste management strategy for industrial parks should prioritize waste reduction, reuse, and recycling (3R). Assessing the various elements and challenges of thermal waste-to-energy in a life-cycle thinking approach is necessary before implementing waste-to-energy options.

Park operators can consider two types of technologies when converting biomass and waste into energy: combustion/incineration and gasification. In the *combustion/incineration*[21] process, heat is generated from burning waste/biomass and can be used to operate a steam turbine, which subsequently generates power. In gasification processes, on the other hand, all feedstock containing carbonaceous material is converted into syngas — a mixture of gases such as carbon monoxide, carbon dioxide, and hydrogen. Syngas is used as fuel for operating a gas turbine and subsequently generating power. Gasification can be achieved by two processes, that is, pyrolysis and anaerobic digestion. Value-added by-products such as biosolids can be recovered during both pyrolysis and anaerobic digestion processes and used as fertilizer (this process is discussed in more detail in chapter 5). Figure 3.7 exhibits key processes of each of these two methods.

Biogas production is an important source of renewable energy in industrial parks and is often part of the industry symbiosis network established in EIPs or between industrial parks and cities. Scandinavian countries stand out for their implementation of biogas projects in industrial parks. In Sweden, the combination of European Directives with national environmental regulations streamlined biogas plant installations at self-declared EIPs. Policies to promote waste segregation, restrict disposal of organic solid and other combustible waste in landfills, and levy a tax on waste incineration were the capstone of the country's success in biogas. Biogas plants are now advanced to produce biofuel by amending innovative technologies.

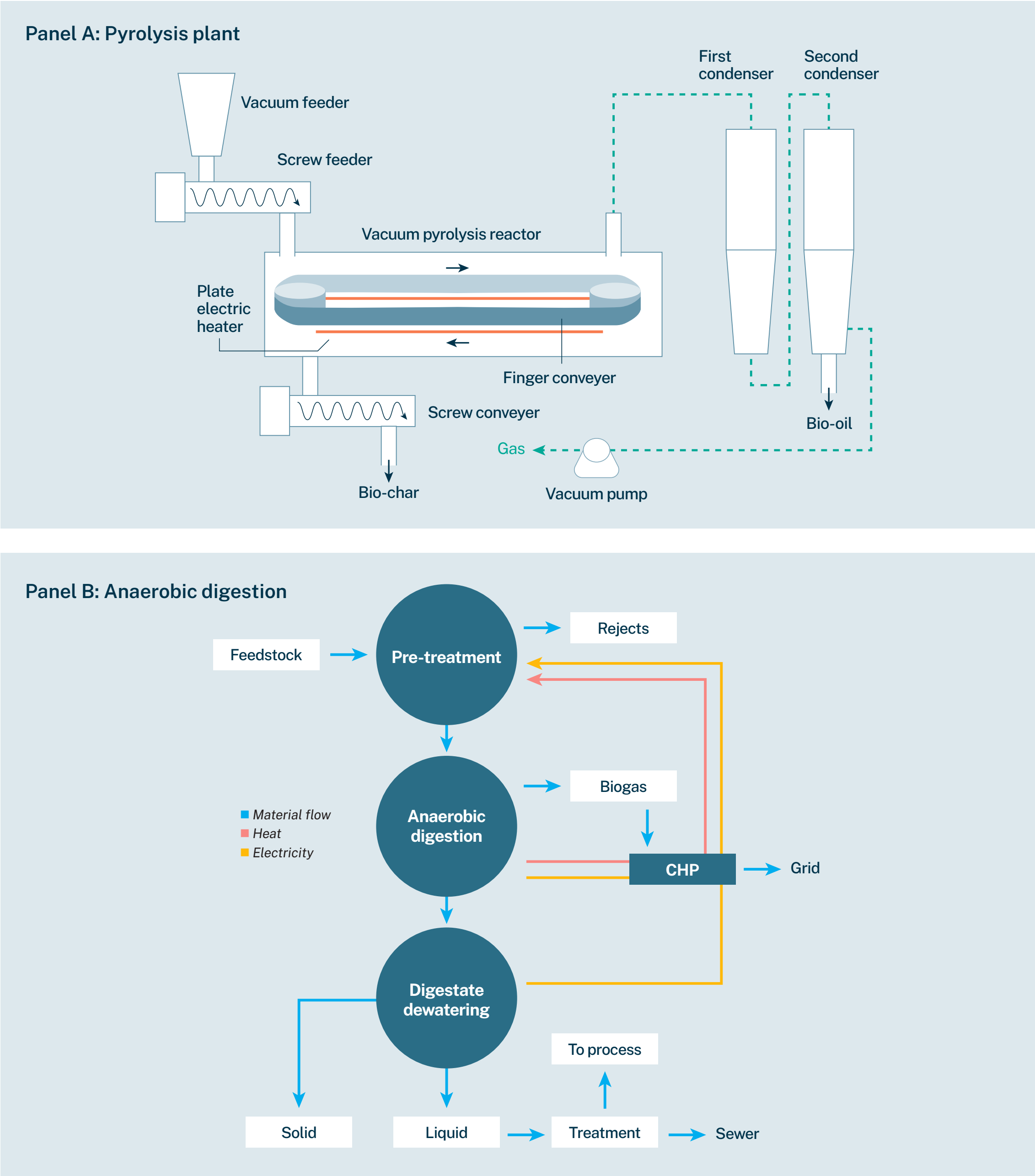
Key considerations for implementation

Park operators need to consider several technical parameters to understand the feasibility of waste-to-energy technologies and optimize the size of infrastructure. Among these, the availability of a steady and consistent flow of biomass or organic waste and sludge is key. Land is also important: a minimum 0.15 acre is needed to establish a 250 kW plant (including dumping, drying, and storage). Other variables to considered include the availability of skilled and trained operators, and proximity to a power distribution network (powerline or gas pipeline).

Economics of technology

The installation cost of a waste-to-energy incineration plant is variable across geographies — $250/ton of annual waste assimilation capacity in China, and $840/ton in the United States (Wu 2018). The costs of gasification plants are significantly higher, with pyrolysis plants ranging from $8,000–$11,500/kW, while anaerobic digestion ranges from $7,500 — $11,000/kW (Tangri and Wilson 2017).

FIGURE 3.7 • Schematic diagrams of pyrolysis and anaerobic digestion variants of waste gasification



Sources: Science Central: https://www.e-sciencecentral.org/articles/Figure.php?xn=jbe/ksam-43-14&id=F001; AZO Cleantech: https://www.azocleantech.com/article.aspx?ArticleID=356.

BOX 3.9

Biogas technology in Höchst Industrial Park, Germany

Overview

- **Location:** Frankfurt am Main, Germany
- **Number of companies:** Approximately 90
- **Sector distribution:** Pharmaceuticals, biotechnology, basic and specialty chemicals, crop protection, food additives, and services
- **Number of employees:** Approximately 22,000
- **Area:** 460 hectares (50 hectares available for new construction)
- **Year of establishment:** 1863 (former main site Hoechst AG)
- **Economic significance:** $9 billion in investment undertaken by tenant firms since 2000; provides employment to nearly 22,000 employees across 90 companies

Background

One of Europe's largest, most successful industrial estates, Industriepark Höchst provides an on-site trimodal port and ecofriendly infrastructure (e.g., modern waste management facilities and efficient energy generation plants that have made the park energy independent). The park serves as an important testbed for biotechnology, automated logistics, sustainable energy production and resource conservation, and modern research methods and production processes. It has been operational for over 22 years and continues to attract investors.

Motivation

Industrial bio solids are typically poorly suited for anaerobic digestion and biogas production. However, their composition has gradually changed at Industriepark Höchst through the years, partly due to the modernization of the park's wastewater treatment and pretreatment plants, and partly to alterations in its wastewater mix. New facilities started generating easily biodegradable wastewater. Many resident companies have also optimized their production processes—not only do they produce less wastewater, but they have incorporated pretreatment to keep undesirable constituents from reaching the wastewater treatment plant. This changing environment has motivated the park to develop a creative circular economy solution that not only improves sustainability but also generates an additional source of revenues (Process Technology Online 2006).

Circular economy solution and technologies

Leveraging this changing environment within the industrial park, the park operator introduced a first-of-its-kind co-digestion plant that generates biogas from industrial bio solids and produces 30,000 cubic meters of biogas by converting organic constituents of bio solids and organic wastes through the digestion process. The unit consists of two digestion tanks, a combined heat-and-power plant, two nitrification tanks, and two sludge thickener tanks. It has a capacity of handling 310,000 tons per annum (tpa) of sewage sludge and 190,000 tpa of cosubstrates.

The process begins with the codigester, which sustainably breaks down the organic matter. The residual sludge is compressed and then incinerated for energy recovery in a sewage sludge incineration plant. Used process water is treated at the wastewater treatment plant. The generated biogas is used to produce electricity and steam (in a combined heat and power plant) along with biomethane (injected in the national gas grid) (figure B3.9.1).

Economics:

CAPEX: $18 million

Financing: Cost borne by park operator, that is, Infraserv Höchst

Enablers

Germany is the largest biogas market worldwide, with enabling policies like the Renewable Energy Act in 2004, which provided subsidies for renewable energy sources through assured long-term feed-in tariffs. The act created advantageous conditions for the access of biogas to electricity markets and grids, as well as measures to secure the investment and financing of biogas plants through adequate renumeration. The higher-level goals of the Common Agricultural Policy played an important part in making biomass available to facilitate biogas generation capacity (Thrän et al. 2020).

Additionally, the organizational structure of the park operator, Infraserv, supports the competitiveness of tenant firms, several of which have a majority stake in Infraserv and supervise its activities. This has helped elicit a more active response from the park operator in facilitating the setup of this plant. In fact, Infraserv considers the industrial site as an innovation campus and invites start-ups and other actors to test innovative technologies based on the use of the existing resource and waste flows (for example, Ineratec).

Results

Amount of recovered waste and resources: 310,000 tons per annum (tpa) sewage sludge

Lessons learned for park operators

The role of park operators in such a setup includes background operational activities, that is, collection of waste material from source, testing waste for digestibility before acceptance, managing waste treatment process (this includes waste digestion and biogas generated used in combined heat and power [CHP] plants followed by residual sludge compression and incineration and finally used process water treatment in water treatment plants) and distribution of power, steam, and biomethane to tenant firms.

Applicability in developing countries: High

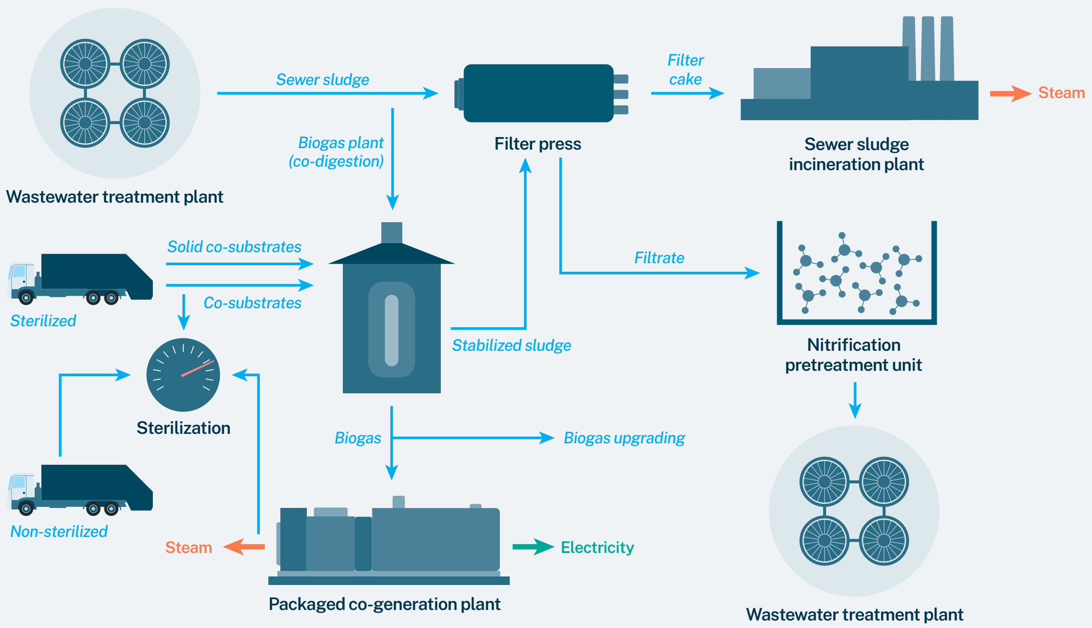
Strengths: Provides additional revenue-generating opportunity for the park operator

Weaknesses: Technical viability depends on waste type and requires in-depth study to establish; active participation of park operator required in designing, installing, and operating the system as well as onboarding client firms

Required enablers: Incentivizing use of biogas

Sources: Höchst Park information: http://www.industriepark-hoechst.com/en/stp/menu/the-industriepark-hoechst/; https://www.industriepark-hoechst.com/en/stp/menu/powered-by-infraserv/services/disposal/biogas-generation/; and other information shared by Infraserv Hochst.

FIGURE B3.9.1 • Schematic diagram of biogas generation plant



Source: Infraserv at Industriepark Höchst.

Operational challenges

Park operators need to consider the following operational challenges and concerns when adopting waste-to-energy technologies:

» **Negative environmental externalities associated with waste incineration:** Pollution caused by an inappropriate control system and improper implementation of pollution control measures is the key concern of a waste-to-energy system, especially for incineration technologies.

» **Power generation's dependence on a consistent type of waste:** A lower calorific value of waste due to improper sorting and collection can lead to less energy retrieval from it. Lenders and investors depend on current and future waste composition, so waste quality is a key risk factor. For example, Southeast Asian waste can have a significant amount of "wet" material in it, such as food waste. This is harder to burn, provides a lower caloric value, and can vary from year to year. For incineration plants, this means a fluctuation in electricity output and revenue uncertainty (Lim, Yuen, and Bhaskar 2019).

» **Feedstock supply dependent on consumption volume:** Ensuring the availability of feedstock is a key concern. Establishing linkages with sources of a constant stream of waste with appropriate calorific value is required before setting up such a plant. Waste generated within the industrial park itself may not be sufficient.

Key enablers

» **Partnerships with local municipalities:** Potential partnerships with local municipalities can create synergies in optimizing the volume of biomass/waste available for use by the energy plant. This creates a more stable balance between the supply of energy and availability of feedstock (for example, the cooperation between the city of Malmo, Sweden, and the local industrial park[22]).

» **Regulations preventing indiscriminate waste disposal:** These can help promote the uptake of sustainable waste management practices. Developed economies have directives on landfills (e.g., EU Directive 1999/31/EC and ancillary legislations[23]), including restrictions on items that can be disposed in them (e.g., US state-specific legislation banning certain items[24]). Similarly, developing economies have introduced guidelines on landfills (e.g., India[25]) or have communicated targets to increase waste-to-energy plants, backed by appropriate legislation (e.g., Vietnam[26]).

» **Access to finance:** Financial support provided the government[27] can help increase the penetration of such technologies. Support can come in multiple forms like capital subsidies, grants-in-aid (as in India), or as subsidies and tax incentives (Thailand). For example, the Ministry of New and Renewable Energy (MNRE), Government of India, provides grants-in-aid to the tune of $0.41 million/MW for waste-to-energy plants and $0.14 million/12,000 cubic meters per day to biogas plants.[28]

3.4 • Key takeaways for park operators, and policy recommendations

Affordable renewable energy technologies are critical for mainstreaming a circular economy approach in industrial parks and helping parks and tenants increase competitiveness while reducing their environmental and carbon footprints. Transitioning from current practices to such circular-economy-based technologies will require innovative business models and support from park operators, including through the following activities:

» **Provide energy supply directly through captive power generation or energy supply services to the firms** complying with local regulations for power generation, transmission, and distribution. Effective business models need to be chosen, reflecting regulatory landscape and prevailing market trends.

» **Implement a certified energy management system** to enable clear understanding of energy consumption patterns within the park and identify and reduce sources of wasteful energy consumption.

» **Explore for synergies beyond park boundaries and in surrounding areas,** including nearby urban agglomerations or other industries. For example, it is possible to reuse sewage sludge to generate biogas or use municipal solid waste for power generation in an industrial park.

» **Act as demand aggregators for tenants.** For instance, park operators can aggregate demand to install rooftop PV for captive renewables and procure larger quantities at competitive prices.

» **Develop a clear understanding of financial support and financing mechanisms** available for parks and tenant firms to implement cleaner energy systems at a competitive cost.

» **Provide market intelligence support for renewable technologies.** Guide tenant firms by compiling technology options or market-related information needed for prioritizing and adopting these options (e.g., a list of available technology suppliers, operators, and technically competent consultant firms who can conduct high-quality feasibility assessments).

Governments need to also create the right market conditions and incentives to encourage park operators and tenant firms to invest in and adopt innovative business models and technologies. Examples of recommended actions for both park operators and policy makers are provided in table 3.4.

TABLE 3.4 • Policy recommendations to catalyze the adoption of renewable energy solutions and technologies in industrial parks

Area of action	Barriers	Examples of policy interventions
Energy market reform	» In regulated markets, increases in the costs of energy generation are not passed on to consumers, thereby removing the incentive for greater efficiency in the power market.	» Revise the cost structures of power utilities to create upward pressure on the cost of grid power, thereby encouraging park operators and tenant firms to switch to more affordable renewable sources.
Captive generation strategies	» Renewables-based captive power generation has high capital costs, especially investment in grid-scale renewables for the purpose of energy sale.	» Improve access to third-party renewables suppliers by promoting renewable energy service companies (RESCOs). » Introduce net metering to enable tenant firms to offset on-site renewable generation against total consumption.
Managing adverse environmental externalities	» Incinerators — the most common variant of waste-to-energy (WtE) technology — are often known to increase pollution despite environmental safeguards.	» Increase vigilance in waste management, segregation, disposal, and landfilling through selective bans and taxation, thereby arresting adverse environmental fallouts related to WtE.
Financial and fiscal incentives	» The absence of adequate financial and tax incentives makes renewable energy not viable (KPMG 2015) in comparison to cheaper fossil fuel alternatives.	» Leverage dedicated funds for clean technologies and market-based instruments like green bonds to augment financial resources for renewables. » Design fiscal and financial incentives like investment tax credits (ITCs), production tax credits (PTCs),[29] capital and interest subsidies, etc. » Arrange for grants to economize project preparation and feasibility efforts.
Technology proliferation	» Leading best practices on renewable technology research and development (R&D) and project implementation are typically limited to select countries, suppliers, or implementing entities; more active cooperation is needed to promote widespread adoption.	» Promote indigenous R&D and piloting of renewable technologies to serve bespoke needs with the support of development funding institutions. » Develop dedicated knowledge and technology transfer platforms to match energy needs with bespoke renewable solutions. » Foster bilateral and multilateral cooperation to promote investments in clean technologies.

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Endnotes

1. ISO 50001. This is less than the total number of EIPs that have environmental management systems equivalent to ISO 14001, which is 246. https://www.iso.org/iso-14001-environmental-management.html.
2. The growth of ESCOs in China is due to a policy push of legally binding energy reduction targets under the country's 1000 Enterprises Program. In industries, unlike the buildings sector, energy conservation measures depend on the process involved, which varies by industry and type of products and is rarely uniform. In the case of China, the policy push has created a substantial market demand for energy conservation measures in each specific sector, creating a business case for entrepreneurs to invest in developing industry-specific capacity for ESCO services.
3. Emissions trading systems usually involve legislation capping emissions on specific sectors and creating a provision for buying or selling emissions allowances, ensuring that underachievers can buy allowances to meet their emissions limits, while overachievers can sell allowances to generate additional revenue.
4. Renewable energy certificates (RECs) are accompanied by a mandate requiring power utilities to source a part of their supply from renewable sources. Like emissions trading systems, utilities can trade RECs to sell excess capacities in case of overachievement or buy RECs to achieve mandated levels of renewable sourcing.
5. The LCOE measures the lifetime cost of installing an energy generation system (like a solar power plant) divided by energy production. It takes into account installation costs, O&M costs, financing costs, the inflation rate, and the power generated over the lifetime of the system to estimate the cost per unit of power generated, that is, USD/megawatt-hour (US DOE 2015).
6. About performance-based incentives: https://www.seia.org/initiatives/performance-based-incentives#:~:text=Performance%2Dbased%20incentives%20(PBI),over%20a%20period%20of%20time.
7. Industriepark Höchst is piloting this technology. It is a building hydrogen refueling station for fuel-cell-powered vehicles (Industriepark Höchst 2019).
8. Discoms pay the producer at the FiT in gross metering while collecting revenue at the conventional power tariff. In case of net metering, notional payment is at the level of a conventional power tariff (since discoms' power supply is reduced by the amount of solar power generated at the consumers' end). In case the FiT is lower than the conventional power tariff, park operators shall incur higher power bills through gross rather than through net metering.
9. India's Draft Electricity Rules 2020 recommend residential solar installations with a capacity over 5 kilowatts peak (kWp) to have gross metering facilities only (Nair 2020).
10. The global installation cost level was at $995/kW in 2019, with variations ranging from the lowest cost of $618/kW in India to $2117/kW in Russia. O&M costs, on the other hand, varied between $14/kW for Europe and $7–9/kW for India. For further details, see IRENA 2020a).
11. The decline in the competitiveness of industries in Bangladesh is due to following factors:
1. Increase in minimum wages of workers: for example, minimum wage for the RMG sector, a leading industrial sector in Bangladesh which contributes nearly 11 percent GDP, increased by 51 percent in 2018.
2. Loss of favorable trading status: Bangladesh is expected to graduate from the least-developed country category in 2024, which will lead to loss of trade benefits.
3. Rising energy prices: Natural gas prices for the industrial sector increased by 38 percent in 2019, after increases in 2015 and 2017. Gas prices are set to increase further with domestic gas reserves expected to be exhausted by the 2030s and a policy decision to rely on imported liquefied natural gas to supplement national consumption.
12. About CST (US DOE): https://www.energy.gov/eere/solar/concentrating-solar-power.
13. Comfort applications depend on human perceptions of comfort and well-being related to temperature and air quality, which differ with geographical location and seasonal variations. Industrial or commercial applications are fixed by the particular processes being performed or the products being stored.
14. Panel efficiency increased from 13.8 percent in 2010 to 18 percent in 2019 (IRENA 2020a).
15. The prices of battery storage are expected to fall by 40 percent by 2030 (Cole and Frazier 2019).
16. In 2017 alone, solar power projects received $60.8 billion worth of subsides globally (Taylor 2020).

17. Converted to US dollars ($) at the 2020 annual average exchange rate of $1 = ₩1,179.20, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates. ₩= South Korean won.
18. Nearly half of all growth in US renewable electricity generation and capacity since 2000 is associated with state RPS requirements and about 30 percent of all US renewable electricity capacity additions in 2018 can be attributed to RPSs (US EIA 2019).
19. Cut-in speed is the wind speed at which blades start rotating and generate power. The higher the speed, the higher the power generation until the unit reaches the cut-out speed, at which the turbine shuts down to prevent structural damage. Typically cut-in and cut-out speeds are 3.5 meters per second (m/s) and 25 m/s, respectively, although specific values depend on the technical specifications of the turbine.
20. While turbine prices in 2019 varied between $560/kW and $830/kW, total installation costs fluctuated between $1,055/kW and $2,368/kW across geographies. The average global installation cost of wind turbines in 2019 was $1,473/kW. O&M costs for onshore wind often make up a significant part (up to 30 percent) of the LCOE for this technology. However, the O&M costs are declining due to increased efforts of turbine original equipment manufacturers (OEMs) to secure service contracts given potentially higher profit margins in servicing than in turbine supply.
21. In EIPs waste-to-energy is designed to minimize GHG emissions by using organic waste from municipalities or food processing industries to produce biogas or thermal energy.
22. Urban Baltic Industrial Symbiosis: https://ubis.nu/about-industrial-symbiosis/.
23. For further details, see the European Commission Waste Disposal Directive: https://ec.europa.eu/environment/waste/landfill_index.htm.
24. For further details, see Granger (2017).
25. For further details, see Ministry of Housing and Urban Affairs, Government of India (n.d.).
26. For further details, see Das (2018).
27. See ET EnergyWorld (2020b) for the case of India; and Lim, Yuen, and Bhaskar (2019) for Thailand.
28. For details of central financial assistance, see MNRE (2021).
29. Under ITCs, a renewable power developer can deduct a predetermined part of investment, in addition to depreciation, for tax calculations. Under PTCs, utilities are provided tax credits based on power generated and sold from renewable sources.

4 Water

4.1 • Overview

Like energy, water is also a key resource for economic and social development, including industrial production. Apart from fulfilling our physiological needs, it is required for various processes in residential and commercial operations (the majority of them concentrated in urban areas), agriculture, and industries. As per 2019 data, agriculture accounts for 69 percent of global water withdrawals; industries and households account for 19 percent and 12 percent, respectively (UNESCO 2019). Amid global population and economic growth, water consumption is set to increase by 20–30 percent by 2050. Much of this growth is expected to come from industries and households, whereas agricultural demand is expected to go down (UNESCO 2019).

The availability of water, however, is not increasing in sync with demand, resulting in high levels of water stress[1] for over 2 billion people in 22 countries. If the degradation of the natural environment and pressure on global water resources continues at the current pace, 45 percent of the global gross domestic product, 52 percent of the world's population, and 40 percent of global grain production will be at risk of facing high water stress levels by 2050 (UNESCO 2019). Yet, given the current trends of population growth and the intensification of climate change impacts, levels of physical water stress are likely to increase.

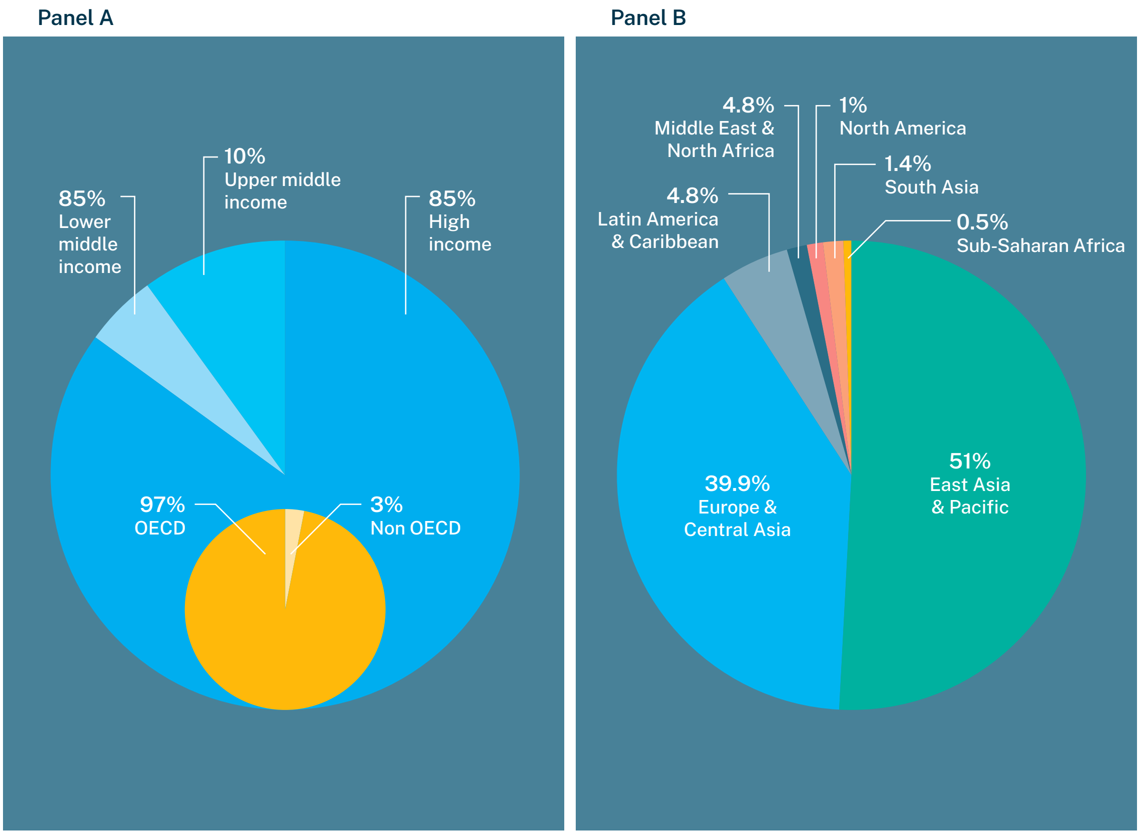
To proactively address the water scarcity problem, industries can adopt technological developments such as on-site recycling of wastewater and advanced cooling technologies that reduce water consumption. Where these technologies are employed in eco-industrial parks (EIPs), they have helped reduce the water footprint in various industry sectors.

This chapter focuses on innovative solutions that have improved the efficiency of water use in EIPs, which in turn enhances the sustainability and competitiveness of both tenant firms and the parks overall. These solutions can be implemented at two stages: that is, water supply and post-use ("wastewater treatment"). Understanding the differences between the solutions applicable at these two phases is essential before proceeding with a discussion of water efficiency in EIPs. Water undergoes a treatment process at both supply and discharge points to ensure its adequate quality in line with the purpose of its utilization. Water-efficient technologies facilitate this process within the parameters of climate-responsive design.

Water supply technologies discussed hereon help minimize the withdrawal and use of finite water resources (e.g., groundwater) by enabling increased utilization of renewable water sources (e.g., rainwater) and conventionally unusable water sources (e.g., saline water). Wastewater treatment technologies, on the other hand, aim to minimize wastewater generation and increase opportunities to properly treat and reuse wastewater. The design of a water supply and wastewater treatment system is determined by these end goals. For example, wastewater treatment plants (WWTPs) are designed based on the hydraulic loading[2] and pollution load,[3] while water treatment plants are designed based on the water quality characteristics required by end users (specific industries in this case). To be efficient, the system design of a wastewater or water treatment plant involves innovative technologies, as illustrated in this chapter.

According to a World Bank (2020a) survey, 47.5 percent (or 208) of the 438 surveyed EIPs have adopted water efficiency improvement practices that include wastewater reuse, rainwater harvesting, innovative membrane technologies for recycling water in a centralized effluent treatment plant (CETP), and zero liquid discharge systems. High-income countries, including members of the Organisation for Economic Co-operation and Development (OECD), stand out for their use of innovative water management technologies targeting both supply and treatment (figure 4.1).

FIGURE 4.1 • Distribution of water-efficiency technologies based on regional income groups and geography



Source: World Bank 2020a.

EIPs that are publicly owned and operated are most likely to adopt measures to improve water efficiency. Among 208 self-declared EIPs that adopted water efficiency practices, 66.3 percent are publicly owned (290 EIPs), 25 percent are private (109 EIPs), and 8.7 percent (39 EIPs) were developed as public-private partnerships. This finding suggests that the adoption of water efficiency measures in industrial parks still largely requires public support.

Existing wastewater treatment practices may be inadequate to maximize the reuse of industrial wastewater. A World Bank survey found that at least 148 EIPs (33.7 percent) have their own in-house CETPs, 13 of which have a direct connection to the municipality's sewer network (World Bank 2020a). The CETPs installed in these parks collectively process industrial wastewater generated by individual tenant firms. These firms often have mixed industry profiles, ranging from light industries (e.g., leather and textiles, food processing, electronics manufacturing) to heavy industries (e.g., steel and chemicals), and do not adopt pretreatment systems. This results in a complex pollution load in their wastewater, with high concentrations of organic pollutants, heavy metals, and toxic chemicals, which require more sophisticated and capital-and energy-intensive technologies than does municipal wastewater.[4]

Park operators would do well to identify various types of innovative water supply, as well as wastewater treatment and reuse practices, and prioritize those that best suit the specific characteristics of their industrial parks. The following section elaborates on innovative practices and technologies adopted in EIPs to promote circular water supply and treatment systems including rainwater harvesting, desalination, zero liquid discharge, membrane systems for circularity, and other sustainable solutions.

4.2 • Water supply technologies

In industrial parks, tenant firms are provided with water from naturally occurring sources (such as rain, underground reservoirs, wells, lakes, and rivers) or municipal water that is treated according to the specific local characteristics and demands of the parks and their tenant firms. The most common postsupply water treatment systems used in industries are raw water treatment systems, boiler feedwater treatment systems, and cooling tower water treatment systems.

Circular economy approaches are critical in industrial parks and EIPs operating in water-stressed areas, especially in minimizing the withdrawal of depletable freshwater and maximizing water/wastewater reuse. Three technologies stand out for providing innovative and cost-effective solutions in water-stressed industrial parks: rainwater harvesting, desalination, and membrane technologies.

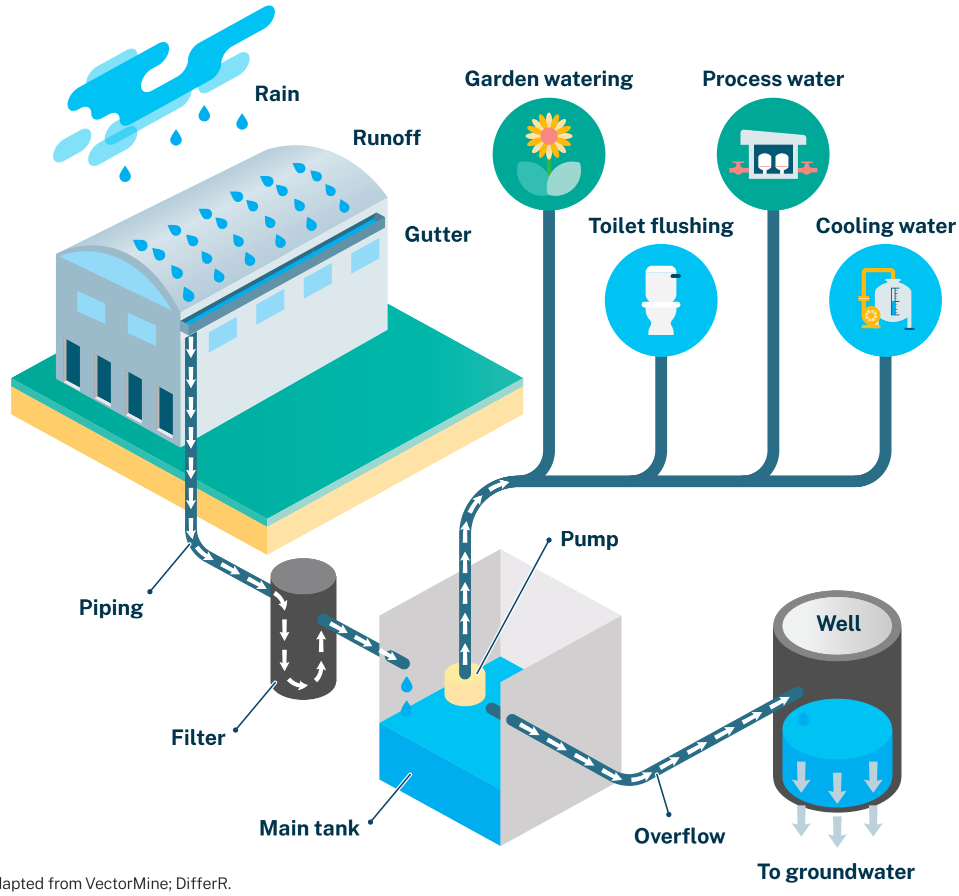
4.2.1 • Rainwater harvesting

Rainwater harvesting is a process that directly captures rainfall from roofs or catchment areas, and stores and reuses stormwater collected in industrial parks (figure 4.2). It helps reduce water consumption by reusing stormwater and increasing the circularity of water resources within industrial parks. It can also be used as a backup supply for regular water services, thus enhancing their reliability (World Bank 2020b). Park operators can consider the following two ways of collecting and harvesting rainwater:

» **Large-scale stormwater harvesting** captures water runoff through storm drains. Collected stormwater may contain pollutants as it flows across impervious surfaces. These pollutants need to be removed through a treatment process to meet the specific requirements of end users (in this case, tenant firms) before being distributed. The type of treatment required for stormwater depends on the end use — only filtration and disinfection are required for low-quality water use (e.g., for construction or fire protection), while for higher-quality water use (such as potable/drinking water), the treatment process will require more complicated steps including screening, coagulation, filtration, carbon adsorption, and disinfection.

» **Rainwater harvesting** involves the collection of rainwater from roofs. Rainwater is less polluted than stormwater and requires minimal treatment for industrial users. The water is collected and stored in tanks, and can be used for gray water, fire protection, and irrigation. Rainwater harvesting can complement existing water supply systems installed in industrial, parkwide, or single-building systems.

FIGURE 4.2 • Schematic diagram of typical rainwater harvesting system



Source: Adapted from VectorMine; DifferR.

Key considerations for implementation

To implement a rainwater harvesting system, park operators need to understand the demand for and end uses of the captured water. This will determine the type of treatment processes required; they also need to assess areas available for capturing and storing rainwater, that is, the roof or other open areas. They should also consider meteorological factors affecting the runoff volume (e.g., annual rainfall in the projected area, seasonal variations, and evaporation rate), and physical factors affecting runoff (e.g., surface runoff coefficient, slope, topography, vegetation, etc.). The availability of these data (e.g., historical data on annual rainfall in the project area, seasonal variations, and evaporation rate) and capacity to monitor and collect these data at the national, local, and park levels need to be also checked. The presence of local suppliers for filter systems, pumps, storage tanks, backwash system filters, and storage tank ventilation and treatment (e.g., filtration, disinfection) also has implications for the technical feasibility of a rainwater harvesting system (US DOE n.d.).

Economics of the technology and financing mechanisms

The capital costs of setting up a rainwater harvesting unit depend on the factors mentioned above as well as size and design elements, such as the catchment surface where runoff water is collected, the type and size of a storage reservoir, and a reticulation system — that is, the gutters, channels, and pipes used to transport water from catchment to storage area. In developing countries such as India, the indicative capital cost of setting up a rainwater harvesting system is $1– $1.5 per square meter (m^2) (CSE n.d.).[5] Typically, underground reservoirs incur a significantly higher cost than above ground systems due to the added cost of excavation and the system design, which requires structural integrity.[6]

Financial returns from investment in a rainwater harvesting system also depend on water tariffs — that is, the prices assigned to water supplied by a public utility and/or industrial park operators. Water tariffs, in turn, depend on government tariffs on water use, as well as the geographical location of industrial parks.[7] Industrial parks in arid and water-scarce regions may prefer to install a parkwide rainwater harvesting system to complement the supply of process water from the existing network and wells, which is often very costly. Industrial park operators need to balance all these factors to increase their financial returns on investment and attract potential private investors.

Rainwater harvesting systems are simple in operation and can, in general, operate with minimal maintenance or operational costs. Operational costs involve occasional (annual/monthly) cleaning of the reservoir along with maintenance of pumping systems and replacement of filters and can be relatively small (US DOE n.d.). Key risks during the operational phase include uncertainties associated with changes in rainfall patterns in the project area, and how these might affect the quantity of water that can be captured. As highlighted by the Intergovernmental Panel on Climate Change (IPCC), the impact of climate change will increase overall global precipitation levels, which can vary greatly by region.[8] Park operators can undertake independent projections based on regional rainfall patterns to verify any rainfall variations during the project period.

Although the returns on investment may vary depending on the factors mentioned above, a rainwater harvesting system generally has a short payback period and can provide a cost-effective means of water supply. For instance, according to the World Bank Group's technical assessment conducted in 2017, ASO OIZ 1[9] in Ankara, Turkey — using a rainwater harvesting system that has a pretreatment feature for supplying process water — was found to be economically viable, provided that competitive water tariffs involved a short payback period. The estimated investment cost was $4.7 million. Considering a water tariff of $4.49 per cubic meter ($m^3$)[10] and an electricity price of $0.054 per kilowatt-hour, the system had a payback period of 2.24 years.

FIGURE 4.3 • Typical rainwater harvesting system

Photo credits: illarionovdv (left); hamik (right)

Key enablers

A number of enabling policies are also required to scale up the adoption of rainwater harvesting, including increased water tariffs, tax incentives, or programs to raise awareness of the resource-saving potential of the practice of rainwater harvesting. Malaysia is a case in point. The country has high annual rainfall and high per capita water consumption (209–228 liters/day) (Lani, Yusop, and Syafiuddin 2018). A significant 36 percent of this demand is from the industrial sector (FAO 2016). In order to stem the depletion of natural water and promote its sustainable use, the country has identified efficient water use as a key action area in the National Policy on Climate Change (2009). In line with this policy, the local government of Johor state in Malaysia applies different water tariffs to industrial consumers based on the levels of water consumption (i.e., 80 and 500 m^3) (DAP Malaysia n.d). This provides a good incentive for industrial parks to invest in rainwater harvesting systems that can help supply process water at a relatively lower cost.

Research and development support can help foster customized solutions and also bring down costs. Domestically developed rainwater harvesting technologies can help maximize rainwater capture considering local conditions. For example, in rain-scarce areas, the collection of surface water (i.e., in catchment areas) can be undertaken. A key point is the slope of the catchment area — a greater slope leads to faster runoff and collection in the tank and minimum spillage from the catchment. However, if the area for constructing tanks is limited, alternate storage/use options can be developed.

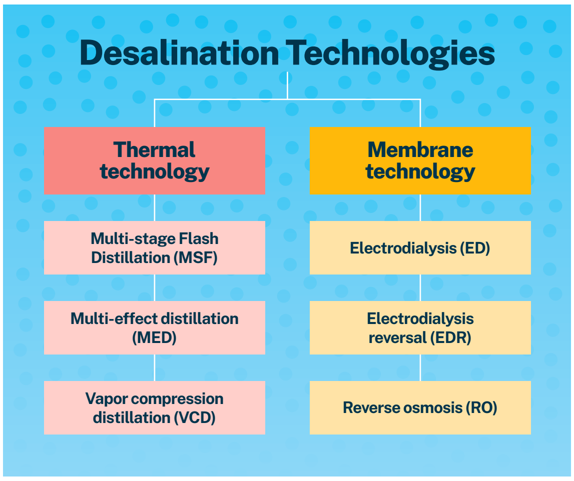
4.2.2 • Desalination

Desalination is another important circular economy strategy that helps parks alleviate excessive groundwater use and supply water in a sustainable manner, especially in regions that have access to seawater but a limited quantity of freshwater[11] (Mauter and Fiske 2020). Parks can generate both process and potable water from desalination and supply it to tenant firms, employees, and local communities. The level of salinity of process water is an important consideration for industries, especially for those whose production processes involve conveying water at high temperatures (to boilers, for instance) or steam generation and usage. In such cases, increased salinity leaves salt deposits in pipes and boilers, which harden over time to form scales. Such scales reduce equipment efficiency and increase the energy requirements for heating water to desired temperatures. Desalination technology is used for treating brackish and saline water whose levels of salinity range between 0.05 and 5 percent,[12] and extracts dissolved minerals and mineral salts from water with a high salinity level,[13] making it useable for industries. Desalination, therefore, is especially useful for industrial parks that are located close to saline water sources such as the ocean, estuaries,[14] and brackish lakes.[15]

Many desalination plants are located along the coast, and most of them in the Middle East and North Africa. These account for around 48 percent of desalination capacity, but mostly cater to municipal requirements. Industrial use desalination plants are more prevalent in North America, East Asia and the Pacific, as well as Western Europe, which account for 18.4 percent, 11.9 percent, and 9.2 percent of global desalinated water capacity, respectively (Jones et al. 2018). The regional concentration of desalination practices reflects factors such as the limited availability of alternate water sources, access to finance (including private finance), and energy costs.

Park operators may explore two key desalination processes: *membrane technology* and *thermal technologies* (Krishna 2004) (figure 4.4). In a process using membrane technologies, including reverse osmosis (RO), seawater or brackish water is pressurized against one surface of the membrane, causing salt-depleted water to move across the membrane, and releasing clean water from the low-pressure side (figure 4.5). Thermal desalination technologies, on the other hand, use heat to evaporate salinized water and separate dissolved salts and freshwater by condensing the vapors generated. RO is the most widely used variant of desalination technology, accounting for 84 percent of total operational desalination plants and producing 69 percent of total global desalinated water (Jones et al. 2018). RO uses significantly less energy and has a higher water recovery rate than other technologies (Jones et al. 2018). As a result, it often provides economically viable options when applied across a range of feedwater types including those that have high salinity such as brine and seawater (Jones et al. 2018). From the circular economy perspective, RO can be a preferable technology especially for industrial parks that require higher capacities (Jones et al. 2018). Thermal desalination is often a preferred option when it is paired with captive power plants but it can increase greenhouse gas emissions if the paired power plants do not integrate renewable energy sources.

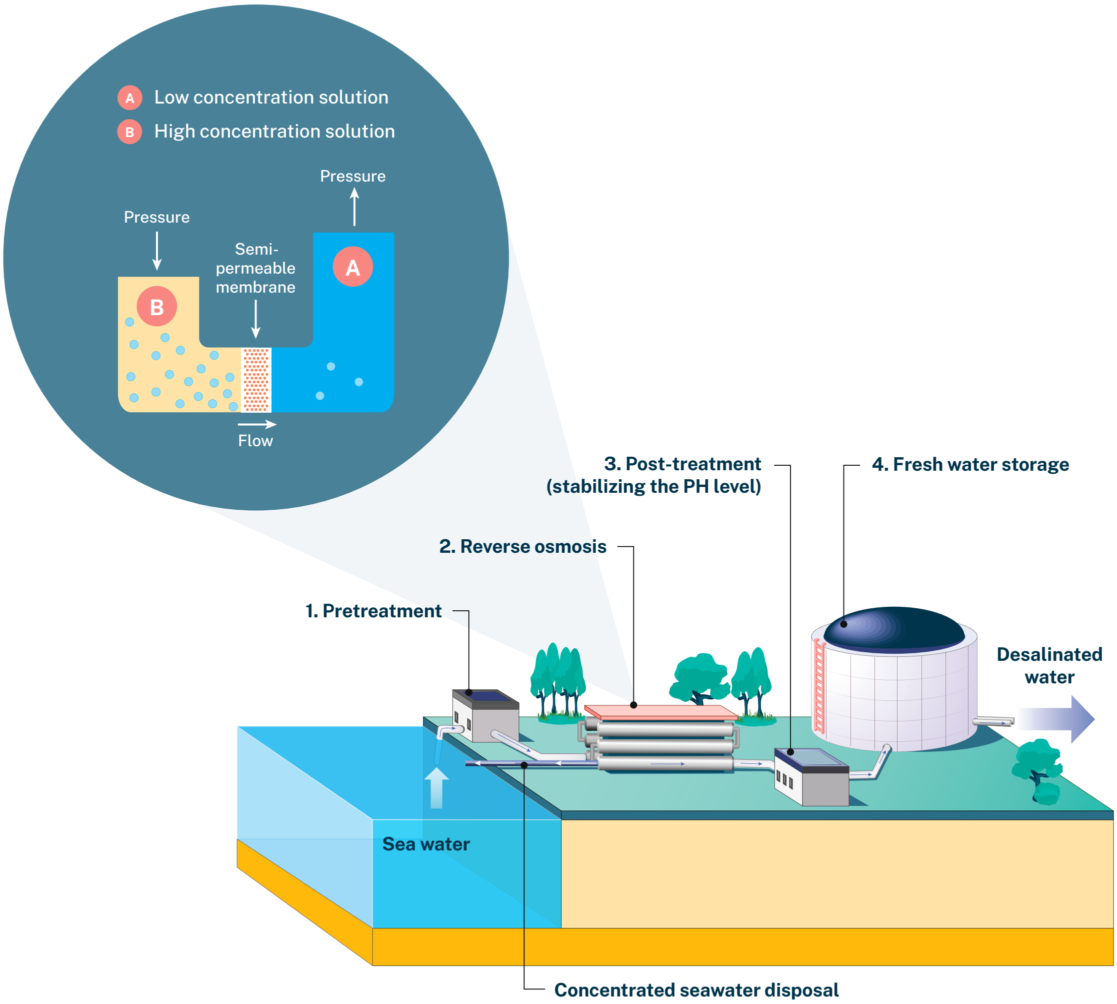
FIGURE 4.4 Categorization of desalination technologies



Source: Krishna 2004.

Further information on the working mechanism of RO plants is given in figure 4.5 and an explanation is given below to aid the decision-making of industrial park practitioners.

FIGURE 4.5 • Schematic diagram of reverse osmosis applied to desalination plants



Source: Nasky (shutterstock) for reverse osmosis diagram: https://www.shutterstock.com/image-vector/illustration-chemistry-osmosis-reverse-diagram-1151850899; Designua for flow diagram of desalination plant: https://www.shutterstock.com/g/designua.

RO uses a high-pressure pump to force a high-concentration solution across the semipermeable RO membrane to generate a low-concentration solution, which has 95–99 percent less dissolved salts than the original high-concentration solution (Puretec Industrial Water n.d.). Proper pretreatment involving both mechanical and chemical processing is critical for an RO system to mitigate its equipment damage, and reduce the frequency of cleaning and system failure (Puretec Industrial Water n.d.). Posttreatment depends on the end use of the desalinated water. In case a desalination plant supplies water to operations that require uninterrupted water supply, water storage facilities can mitigate water supply risks due to the maintenance of water treatment equipment or increased demand.

Key considerations for implementation and operational challenges

To ensure the technical and financial feasibility of desalination, park operators need to check the following factors:

- Projected water demand and characteristics (salinity, pH level) of desalinated water;
- Salinity level and impurities present in saline water obtained from the source;
- Distance between the nearest saltwater source and industrial parks;
- Area available within and around industrial parks for setting up a desalination unit;
- Availability of the most economical power supply option (captive power generation from fossil fuels/renewables or grid power supply); and
- Options available for disposing brine water generated from the desalination process.

The location of the feed water and supply point defines the need for additional investment, including in pipelines, pumps, and auxiliary facilities. It is most cost-effective when these plants are nearby the water supply area. Proximity to water supply also helps in discharging the brine water without a significant ecological impact, thereby reducing disposal-related costs.

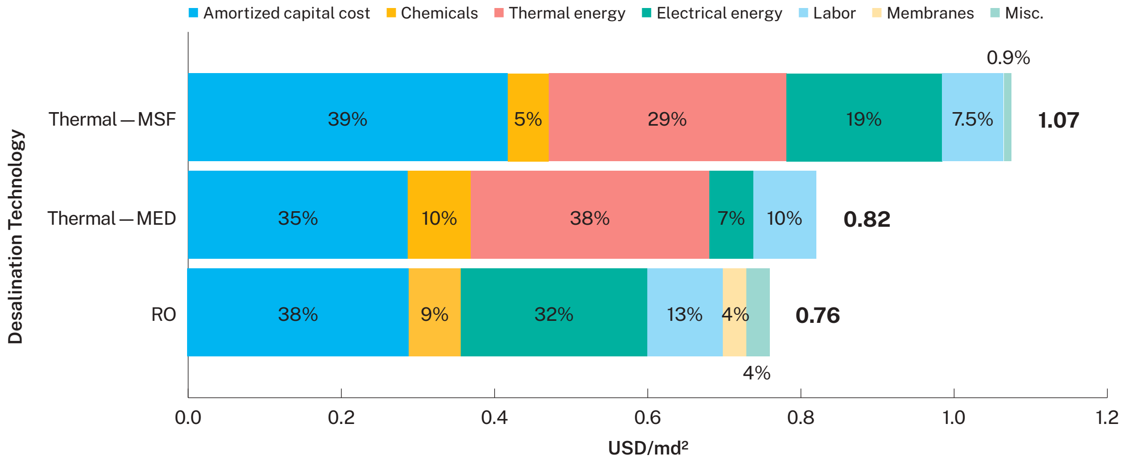
Park operators need to also address a number of operational challenges, such as the high energy consumption of the desalination process. A thermal desalination plant can be combined with power plants and refineries so that it can harness waste heat and reduce fossil fuel consumption. The thermal desalination technology is preferred in industrial parks where relatively smaller capacities of water supply are required. In addition, **discharging brine water after treatment can cause environmental problems**, which can have an impact on the cost-effectiveness of the plant as well. There are multiple ways of disposing brine water (e.g., surface water disposal, submerged disposal, deep-well injection, evaporation ponds, use for irrigation), and in all cases, the high salt content can have a negative impact on marine life or the water table. To reduce these impacts, desalination plants can install brine concentrators or zero liquid discharge units along with desalination units.

Economics of the technology and financing mechanisms

Addressing these challenges has implications for the financial feasibility of a desalination plant in an industrial park. Despite the advancement of desalination technologies, desalination plants are still capital intensive both in terms of capital investments and operational costs.[16] Desalination plants generally require a high up-front investment that accounts for nearly 40 percent of the net cost of generating one unit of desalinated water. Operational costs are also high due to the large volume of energy required to operate the plant. The energy consumed in the process is a critical issue and accounts for more than 40 percent of the total cost of producing desalinated water if thermal desalination technologies are applied (figure 4.6).

Operational costs can further increase if the input water has high levels of salinity (figure 4.7). A high salinity level increases the operating pressure and temperature of the plant, which in turn lowers membrane performance and longevity, thereby increasing operating costs (World Bank 2019). Such impact is especially significant for processes in textile wet processing, food, and pharmaceutical industries that require highly purified water, similar in characteristics to distilled water. The cost associated with discharging the brine water generated from the desalination also increases operational costs.

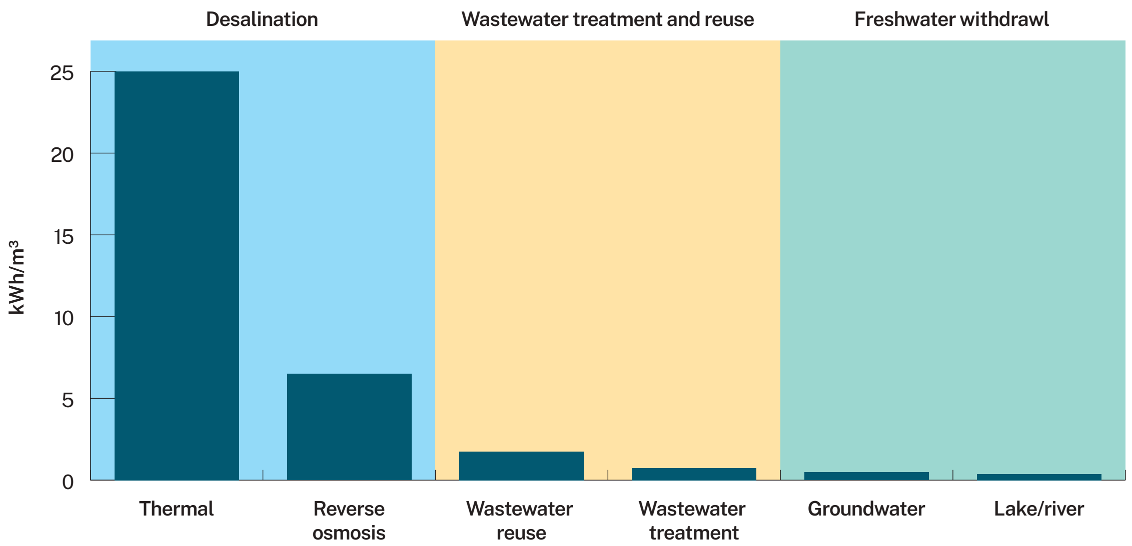
FIGURE 4.6 • Cost breakdown of three types of desalination technologies



Source: World Bank 2019.

Note: Costs assume a $0.05 per kilowatt-hour electricity cost and an oil price of $60 per barrel. ED = electrodialysis; MSF = multistage flash distillation; MED = multieffect distillation; RO = reverse osmosis.

FIGURE 4.7 • Energy consumed per one cubic meter of potable water in different water supply schemes



Source: UNESCO 2014.

Water utilities are often unable to guarantee reliable revenue streams that cover the high investment and operational costs associated with desalination. While subsidies and grants from governments continue to play an important role in financing water and wastewater infrastructure, including desalination plants, a stable revenue stream is required to allow utilities and/or park operators to deliver reliable services at a competitive price and carry out sound asset planning and maintenance.

Therefore, innovative technical designs and business models are crucial to making desalination a viable and meaningful circular economy solution. Desalination plants powered by renewable energy sources, for instance, can reduce GHG emissions associated with operating highly energy-intensive desalination processes. There are over 100 renewable energy desalination systems operating globally, with solar and wind having 70 percent and 20 percent share of such systems, respectively. The cost of producing process water in such systems is much higher than conventional fossil-fuel-based systems (Alkaisi, Mossad, and Sharifian-Barforoush 2017); however, it is expected that with future advancements in renewable energy technology and a drop in system costs, the technical and financial viability of renewable-energy-based desalination systems will improve.[17]

In order to address the issue of inconsistent revenue streams, governments are turning to public-private partnership (PPP) models to encourage the adoption of new desalination technologies and leverage private finance. In Saudi Arabia, for instance, with the support of the International Finance Corporation, the government authority structured and implemented a PPP for developing and operating a new 30,000 m^3 per day desalination plant (IFC 2007). Various forms of PPPs[18] can be considered for water supply and wastewater treatment systems broadly and desalination systems more specifically. While these forms of PPPs have most often supported urban water supply, variants can be explored for the industrial park context.

There are notable examples of urban wastewater reuse for industrial use, facilitated by PPP arrangements. Singapore's NEWater initiative treats urban wastewater through five WWTPs to supply wafer fabrication plants, industrial estates, and commercial buildings. Two of these plants have been developed by private companies under a design-build-own-operate model (Singapore PUB n.d.). In China, Beijing has developed a wastewater reuse network that includes multiple water treatment plants supplying water to nearby industrial parks. While the larger plants are owned and operated by the local government, smaller-capacity plants have been developed and operated under the PPP route (National Institute of Urban Affairs 2016).

Key enablers

To increase the adoption of desalination practices at the park level in a cost-effective manner, a number of enablers may be required:

» **An effective legal and regulatory framework, institutional effectiveness, and real-time demand management.** A combination of these factors has proven to be effective in promoting desalination technology in EIPs, as exemplified in the case of Singapore. As discussed earlier, Singapore is a highly water-stressed country and, to ensure efficient water use, the Ministry of the Environment and Water Resources has developed a strict regulatory framework outlining water quality, drinking water standards, and water tariffs. Also, a dedicated agency, the Public Utilities Board, has been constituted for acquiring, producing, disseminating, and reclaiming seawater through desalination to ensure a sustainable and efficient water supply. The agency has exhibited effectiveness in tackling water issues by enabling research and development of desalination technologies for industrial water supply and undertaking real-time demand management in line with regulatory requirements through constant demand monitoring.

» **Availability of a waste heat recovery system connected with the desalination plant.** Given their high energy requirements, desalination units are often coupled with power plants from which waste heat is recovered and used to operate the desalination processes. To make the system more energy efficient, thermal desalination plants can capitalize on power plants situated nearby to tap into waste heat via steam generators. An example of such an arrangement is in the Shahid Salimi power plant in Iran — waste heat generated from the plant's cycle condenser is used in the desalination plant, which draws water from the nearby Caspian Sea to produce desalinated water for the captive use of the power plant (Shafaghat et al. 2011).

» **Creation of alternate revenue streams.** Technological advancements are allowing the extraction of useful chemicals, including ones that can make the desalination process itself more efficient (sodium hydroxide) and input chemicals for other industries (hydrochloric acid) (Chandler 2019). While adding such extraction units can escalate the capital costs of a plant, it also helps to create alternate income opportunities for park operators, as well as resolve the issue of sludge management.

A notable industrial application of desalination can be found in Jurong Island, Singapore, which houses an EIP along with other industrial units. A desalination plant with a capacity of 137,000 m^3 per day has been installed in the Tembusu Multi-Utilities Complex (ST Engineering 2017; DMS 2019). The plant provides a cost-effective and integrated suite of utility services that include providing steam, high-grade industrial water, and demineralized water to industries operating in the island. Another example of a desalination plant is the Point Lisas Industrial Estate of Trinidad. This case shows how EIP technologies can help not only safeguard the commercial interests of tenant firms but also enlarge the potable water supply for surrounding municipal areas (box 4.1).

4.2.3 • Membrane technologies

Membrane technologies help purify water and treat wastewater, and therefore are critical tools to increase wastewater reuse in industrial parks. A membrane is a physical barrier used to separate solid particles of varying sizes from groundwater, surface water, or wastewater by restricting the movement of the particles through it. There are various membrane technologies; pressure-driven membrane processes (including those that use RO technologies[19]) are by far the most widely applied, since they are applied to both pretreatment (in water supply) and posttreatment of wastewater in industrial parks. Industrial parks that are located close to tributaries can consider and use these membrane technologies to supply water to their tenant firms. Introducing membrane technology creates an added value especially if the feedwater is already a polluted source. The choice of membrane type is dictated by the type and size of the pollutants to be removed from the incoming water stream.

Key considerations for implementation, and operational challenges

Park operators and investors need to consider a combination of factors concerning the plant design and prevailing market capacity that can affect the technical and financial feasibilities of wastewater treatment and reuse systems using membrane technologies. These include:

» Vicinity to feedwater source;

» Pollution level in the sourced water;

» Presence of water-intensive industries operating within the industrial park;

» Availability of skilled personnel to operate and maintain the facility; and

» Availability of membrane technology in local markets to facilitate periodic sourcing.

Park operators need to make sure that manpower, spare parts, consumables (e.g., membranes), and additives (e.g., chemicals and bacteria) are available to operate effluent treatment plants (ETPs) that integrate membrane technologies. Availability of membranes may be low in certain regions, especially in developing countries. The supply of spare parts required for continued operations may also be limited, due to regional variation in the penetration of the technology. In case the membrane-technology-based ETP is installed as a central unit for an industrial park, it should have the capacity to process a mixed type of wastewater discharged by different types of industrial units. The changes in effluent composition can reduce the operational efficiency of the membrane and subsequently, the efficiency of the ETP as well. Hence, the design of such a membrane-based ETP system for an industrial park should take into consideration the long-term effluent composition scenario.

Economics of the technology and financing mechanisms

The capital cost of installing a pressure-driven membrane system in industrial parks depends on the size of the treatment unit, the volume of feed solution to be addressed, and the standards that need to be attained. More stringent standards will require higher capital costs up front, as well as an increase in long-term operation and maintenance (O&M) costs. A substantial part of O&M costs depends on the frequency of membrane replacement, the volume of water pumped, and the operating pressure level. Other expenses such as for purchasing cleaning chemicals and disposing of cleaning residues also add to the O&M costs. As an example, the Water Treatment Plant of the Kennecott Bingham Canyon mines in Utah, United States, with a design capacity of 4.3 million m^3 per year for municipal quality water supply, required $15 million of capital investment and an annual O&M cost of $1.2 million (ITRC 2010). However, costs can vary vastly based on the incoming and outgoing water characteristics in the local region, such as the amount of dissolved contaminants and the pH level of water.

To decide on such a solution, the park operator should estimate the water tariff to be offered to the end users and compare it to the current water tariff. This will require running an affordability analysis. In countries and regions where the pricing policy drives the incremental cost of water, industrial parks consider membrane technologies to supply water for their industries. The return on investment is appealing for those parks that host water-intensive sectors such as textiles, beverages, automotives, and food-processing industries. An example from Turkey illustrates how the membrane technology can help promote circular and efficient water supply in an industrial park (box 4.2).

BOX 4.1

Desalination plant operation in the Point Lisas Industrial Estate, Trinidad and Tobago

Overview

Location: Port Lisas, Trinidad and Tobago

Number of companies: Approximately 103

Sector distribution: Methanol, ammonia, and urea plants; steel plant; and light manufacturing

Area: 862 hectares

Year of establishment: Early 1970s

Economic significance: The industrial estate has attracted an investment of over $2 billion

Background

The Point Lisas Industrial Estate is the hub of Trinidad and Tobago's petrochemical sector. The estate covers 862 hectares and represents an investment of over $2 billion. The estate houses approximately 103 companies, mostly from the petrochemical sector. Industries located there include a steel mill (owned by ArcelorMittal), numerous ammonia plants and methanol plants, melamine manufacturing plants, a urea manufacturing plant, and a natural-gas-to-liquid processing facility. Its utilities include two power stations and a reverse osmosis water desalination plant.

Motivation

Limited groundwater sources were constricting the economic growth of the Point Lisas Industrial Estate, which contributes significantly to the national economy. The Government of Trinidad and Tobago aimed to both enhance economic development and provide water for its citizens by tapping into innovative desalination practices.

Circular economy solution and technologies

The desalination plant, managed by the Desalination Company of Trinidad and Tobago Limited (DESALCOTT), takes raw seawater from the Gulf of Paria, off the country's west coast, cleanses it of its mineral content, and then sells the purified water to the island's Water and Sewerage Authority (WASA), the company's sole customer. Approximately half of the produced desalinated water is then sold back to some 20 processing plants in the industrial park, while the remaining is supplied for municipal uses in South Trinidad. The plant had a capacity of 125,000 m^3 per day when it was established in 2003, which expanded to 155,000 m^3 per day by 2014.

Economics and financing mechanisms

- **CAPEX:** $200 million
- **Financing mechanisms:** Mostly equity investment by promoters of DESALCOTT, supported with bridge financing from the Republic Bank Limited.
- The plant provides higher-purity water (85 parts per million, ppm), while normal water treatment facilities provide water at 200–300 ppm. Accordingly, firms can avoid investment in ion-exchange chemicals plant and are willing to pay more than the existing tariff of around $1–$2 per m^3. In fact, the existing tariff paid by industries helps supply potable water to municipal regions at near-zero cost.

Enablers

The park operator undertook technical studies to identify a business case for investing in a desalination plant, which helped lower the investment costs. The plant provided higher-quality process water to the tenant firms, and as a result, the firms could lower their operating costs by reducing their individual expenses on purifying the supplied process water (BVC 2016). Higher water tariffs still made economic sense to the tenant companies in the aspect, which helped maintain financial feasibility of this project.

Results

The plant design was able to reduce freshwater consumption by 40,000 m^3 per day.

Lessons learned for park operators

Industries are willing to pay a significant amount to avoid an even higher investment in getting water supply of a required quality. The case study shows that the business case is present for park operators to establish a desalination plant, based on the quantity and quality of water required in target industries, and availability and cost of alternative water supply.

Applicability in developing countries: High

Strengths: Provides alternate revenue-generating opportunity for the park operator

Weakness: Significant capital investment

Required enablers: Financial support in capital investment

Source: PLIPDECO n.d.; SUEZ 2002; BVC 2016; DESALCOTT n.d.

BOX 4.2

Process water production with membrane technologies, Bursa Organized Industrial Zone, Turkey

Overview

Location: Bursa, Turkey

Number of companies: 316

Sector distribution: Textiles, machines, metals, food, packaging, plastic rubber, automotive and ancillary, electrical equipment manufacturing

Number of employees: 63,422 (as of December 2018)

Area: 712 hectares (total)

Year of establishment: 1961

Economic significance: First organized industrial zone (OIZ) in Turkey

Background

The first OIZ in Turkey, Bursa started off with 4 active companies on 180 ha in 1971 and has since grown to accommodate more than 300 companies over a 712 ha area. The OIZ was one of the first in the country to set up an environmental management unit in 1997 that provided consultancy services to small and medium enterprises in developing long-term, sustainable competitiveness solutions. The park operator, the Bursa OIZ Directorate, distributes process water, natural gas, and electricity to tenant firms and has a staggered consumption-based tariff.

Motivation

In Bursa province, there are 17 industrial zones beyond the Bursa OIZ. Being the fourth-most-populated province of Turkey, Bursa is seeing intensified competition for freshwater. This could increase the water tariff in the region, and in turn, increase production costs for firms operating in the Bursa OIZ.

Circular economy solution and technologies

In 2007, the Bursa OIZ renovated its conventional wastewater system to include a cost-effective solution for supplying process water to tenant companies. It amended the system by adding a new process water production facility equipped with membranes: ultrafiltration and reverse osmosis units. Through the new system, the OIZ extracts 50,000 m^3 water from the highly polluted Nilufer River located next to the OIZ. After going through the physical, chemical, and biological treatment processes, all the extracted water is sent to advanced treatment units daily. The industries in the OIZ are supplied with 50,000 m^3 of process water daily as a substitute to water from the municipal water network. Wastewater generated by tenant companies is treated by the OIZ's advanced wastewater treatment plant, and the rejuvenated effluent is discharged back to the Nilufer River.

The treatment process of this water circularity system also helps to improve the water quality of Nilufer River, especially at the discharge point, as the discharged treated wastewater is much cleaner than the quality upstream. A plant for treating water from the Nilufer River to produce second-quality water[a] helps increase water circularity. The unit comprises physical, biological, and chemical treatment processes followed by sand filtration, automatic cleaning 200 μm (micron) permeable mechanical filters, and finally the ultrafiltration unit. During the final stage of the system, reverse osmosis units purify the water.

Economics

- **CAPEX for membrane water production facility advancement:** $5.95 million
- **CAPEX for wastewater treatment (two identical units):** $12 million

Business models

The price of the second-quality water ($0.2/m^3) is nearly five times lower than the first-quality water ($0.98/m^3), owing to the lower level of purity. The treated wastewater available from the wastewater treatment plant is sold at prices in the range of $0.12–0.15/m^3, providing an additional source of income for the water treatment plant operators.

Results

Recycling 50,000 m^3/day water from the Nilufer River helps prevent the use of an equivalent amount of freshwater from the municipality's water supply network. This helps in reducing demand pressure on municipal water supply lines as well as improving the water quality of the Nilufer River.

Lessons learned for park operators

Through judicious pricing of freshwater and treated water, park operators can induce changes in the water consumption behavior of tenant firms, reducing consumption of freshwater and increasing reuse of wastewater.

Applicability in developing countries: High

Strengths: Improves cost competitiveness by reusing treated wastewater, which has a lower cost than freshwater. Increases water availability for anthropogenic uses. Considering the high population density in developing countries, the use of such technology can prove to have significant economic and social benefits.

Weakness: Technology-related operational issues (high cost of membrane, limited availability of trained personnel who can operate and maintain the system).

Required enablers: Tariff policy for use of freshwater; financial incentives for setting up wastewater treatment plants.

FIGURE B4.2.1 • A ground-mounted solar farm in Konya OIZ

Source: Bursa OIZ internal sources. *Note:* UF = ultrafiltration; RO = reverse osmosis.

Source: Internal documentation of OIZ based on its own lab measurement. See BOSB website: http://www.bosb.org.tr/bosb-tuketim-0-tuketim_fiyat.html; Bursa OIZ website: http://www.bosb.org.tr/bosb-sayfa-36-su_isleri.html; and Bursa Chamber of Commerce and Industry website: http://www.bcci.org/?page=investment/bosb.asp.

a In this case study, first-quality water refers to freshwater used as potable water for human use; the second-quality water refers to treated water available from the Nilufer River, having lower purity levels and used for industrial purposes in OIZ.

4.3 • Wastewater treatment technologies

Industrial parks require effective wastewater treatment plants and systems. These allow them to remove contaminants from used water before it is discharged into water bodies, reuse treated wastewater for process water, or recover materials from wastewater. The composition of industrial wastewater is highly complex and heterogenous since each production process generates different types of wastes, contaminants, or suspended solids. For example, wastewater from textile mills includes organic wastes (resulting in higher biological oxygen demand),[20] suspended solids, oil and grease, sulfide, phenols, and chromium resulting from various fabric-finishing processes; in contrast, wastewater from food-processing industries is almost completely composed of organic, biodegradable waste and suspended solids with limited chemical contaminants. Selecting the optimal type of wastewater treatment system will depend on the type and quantity of wastes/contaminants present in the water stream. According to a World Bank (2020a) survey, **advanced wastewater treatment, zero-liquid discharge, and heavy and rare earth metal removal/recovery are effective solutions for removing waste from water and increasing the circularity of water resources within industrial parks.**

4.3.1 • Advanced biological wastewater treatment technology

In industrial parks, biological wastewater treatment technologies are deployed to remove organic matters — which are constituted of carbon, nitrogen, and phosphorus — from wastewater streams. These organic matters, mainly present in wastewater from textile, leather, food, and beverage plants, otherwise increase biological oxygen demand in the water stream in which they are discharged. The three most advanced biological wastewater treatment technologies widely used by these industries include a conventional activated sludge (CAS) system, sequence batch reactor (SBR), and membrane bioreactor (MBR). These technologies differ by various factors including their specific treatment processes, the quality of treated water, and the quantity of sludge generated from the processes (table 4.1) (Frankel 2019).

Key considerations for implementation

Adopting advanced biological waste treatment technologies in industrial parks requires an assessment of the following factors, related to technical requirements, market capacity, and the regulatory environment:

- Quantity of wastewater generated by production units in the industrial park;
- Characteristics of wastewater, that is, type and concentration of organic and inorganic contaminants and suspended solids;
- Fluctuations in the incoming wastewater stream, that is, temperature, changes in pH level, or salinity levels of wastewater stream due to change in organic content;
- Required effluent quality based on regulatory standards for wastewater discharge;
- Availability of space for installation and commissioning of WWTPs;
- Sludge management costs; and
- Operation considerations — availability of skilled technical personnel, energy costs, availability of equipment components (especially membranes, in the case of MBR).

TABLE 4.1 • Comparison of advanced biological wastewater treatment technologies

Conventional activated sludge process (CAS)	Sequence batch reactor (SBR)	Membrane bioreactor (MBR)
Process		
Wastewater is injected with oxygen in special aeration tanks, where microorganisms that can compose organic waste are grown. These microorganisms settle at the bottom while clear liquid forms at the top and is removed.	Similar to CAS in process; the only difference is that one tank is used for all stages (while CAS uses multiple tanks).	Combines CAS with the use of a membrane for microfiltration, wherein treated water passes through the membrane to efficiently remove suspended solids.
Quality of treated water		
Inconsistent.	Same as CAS except a lower rate of pathogen removal.	Generally high quality unless the wastewater contains a large quantity of suspended solids.
Ease of operation		
» Relatively easy; can handle different types of loads, and operators are familiar with the technology due to its widespread use.	» Sophisticated control and timing require skilled workforce and more maintenance than CAS. » Prone to problems like clogging of aeration device and discharge of sludge at wrong times. » Dependent on uninterrupted power supply.	» High operating costs due to the requirement of membrane cleaning, use of additional chemicals and power usage, and need for replacing membranes on a regular basis.
Space requirement		
Takes up more space than MBR and SBR.	Key benefit is the limited requirement of space.	Nearly half the size of standard CAS equipment.
Quantity of sludge generation		
Highest sludge generation among the three technologies; effective for use in waste-to-energy plants depending on calorific value of sludge.	Amount of sludge generation similar to CAS but lower.	Lowest rate of sludge generation.

Source: Frankel 2019.

Fluctuations in the characteristics of the incoming wastewater stream can have an impact on the efficiency of microorganisms used for aerobic degradation—differences in pH level, temperature, and so on can impede the degradation process. In such cases, additional costs are required for the installation of systems to ensure the consistency of waste-stream characteristics like equalization, pH, and/or temperature control.

Sludge control is another important consideration for the selection of technology. CAS systems may have lower capital costs than MBRs but generate a significantly larger amount of sludge. Hence, operational costs increase due to pumping, transporting, and disposing sludge, apart from any environmental concerns regarding the type of disposal method adopted. Alternate uses of sludge can also be explored, such as for power generation or as fertilizers (SAMCO 2019).

Economics of the technology and financing mechanisms

Biological wastewater treatment systems involve different types of technologies and are often combined with one another or with other treatment/separation technologies. The cost of a biological treatment system can vary significantly due to these factors, with smaller systems starting as low as $500,000, while high-capacity systems can easily exceed $5 million, considering equipment and installation costs (SAMCO 2019). Since each facility has a unique flow rate, influent wastewater characteristics, effluent discharge requirements, additional required equipment, solids handling equipment, and other site-specific conditions, the cost estimates of biological wastewater treatment systems differ. Indicative costs for each technology are provided in table 4.2 to give a sense of the scale of investments required.

TABLE 4.2 • Indicative cost of biological wastewater treatment technologies

Type of technology	CAPEX1 ($/m³ per day)	OPEX2 ($/m³ per day)
Conventional activated sludge (US EPA 2000)	110–3,000	0.15–0.30
Membrane bioreactor (US EPA 2007)	1,800–5,000	0.40–0.60
Sequence BATCH REACTOR (US EPA 1999)	400–1,500	0.20–0.60

Note: CAPEX based on designed system flow rate, i.e., m^3 per day; CAPEX normally decreases with increased capacity. OPEX based on amount of wastewater treated per day, i.e., m^3 per day.

As discussed earlier, detailed evaluation of facilities is required to derive more accurate estimates; the above estimates provide only indicative values.

Key enablers

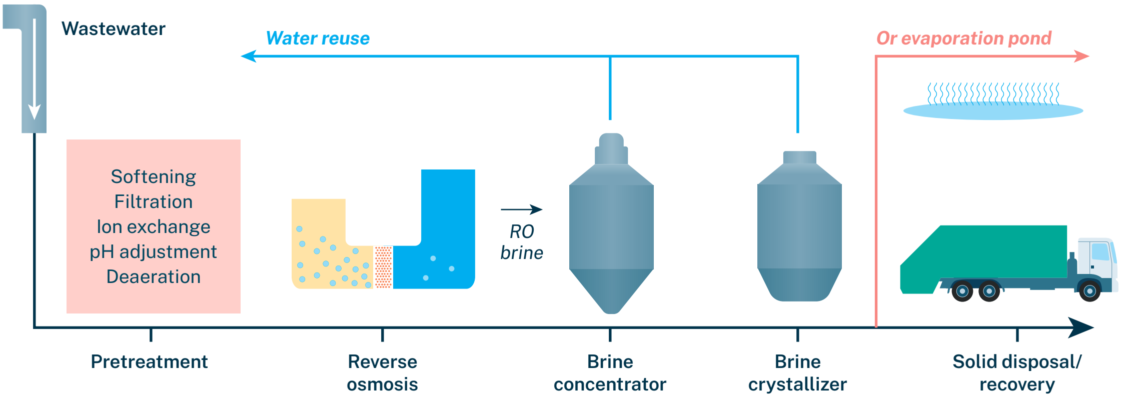
Policy makers can help increase wastewater reuse in industrial parks and facilitate adoption of advanced biological wastewater treatment technologies through various measures such as policy targets, guidelines, and incentives for wastewater treatment and reuse. The role of policies in stimulating the adoption of biological wastewater treatment technologies is exemplified in the case of Mexico. Being a country where water resources are unevenly distributed and are being quickly depleted, Mexico adopted its National Water Law in 1992, encouraging greater efficiency in water use and a more precise accounting of the social, economic, and environmental values of water. The World Bank Group's 2030 Water Resources Group estimated that in 2030, the annual water gap in Mexico could exceed 23 million m^3 (World Bank Group n.d.a), requiring it to increase water efficiency and recycling. To promote the reuse of water, in 2011, the Mexican government launched its Water Agenda for 2030 along with a long-term planning guide for water sector investments. Ambitious targets were set out such as 100 percent water and wastewater coverage and reuse (CONAGUA 2011).

In 2014, the Mexican government (through its National Water Commission, i.e., Comisión Nacional del Agua) developed the "Incentive Program Guidelines for the Operation of Wastewater Treatment Plant," which outlined the financial incentives for WWTP. A grant for installing WWTPs was provided — $0.05/$m^3$ if 30–60 percent of treated wastewater is reused and $0.10/$m^3$ if more than 60 percent of treated wastewater is reused (CONAGUA 2012). These kinds of incentives can catalyze and scale up both public and private investments in CETPs and wastewater reuse systems in industrial parks, thereby helping to mainstream a circular economy approach for park operations.

4.3.2 • Zero liquid discharge (ZLD) system

ZLD is another type of wastewater treatment system designed to remove all liquid waste from a system and generate clean water suitable for reuse, thereby helping industries meet discharge norms and contributing to the efficient use of water. It employs a combination of technologies, through which up to 98 percent of clean water stream can be recovered from wastewater. Figure 4.8 shows the ZLD process to convert effluent water to treated water fit for industrial use (SAMCO 2017a; Bionics n.d.).

FIGURE 4.8 • A Schematic diagram of a ZLD system



Source: Tong and Elimelech 2016; Yaqub and Lee 2019.
Note: RO = reverse osmosis.

Key considerations for implementation, and operational challenges

To facilitate implementation of ZLD technologies, the following parameters are required to be assessed:

- Requisite quality of water (i.e., level of contaminant of treated water);
- Prevailing regulations mandating implementation of ZLD systems;
- Volume of dissolved material present in the wastewater;
- Desired wastewater flow rate of the system;
- Characteristics of the contaminants present in the water stream;
- Available sludge disposal options (e.g., availability of clinker manufacturer to sell dried sludge); and
- Operation considerations — availability of skilled technical personnel, energy costs, and equipment components (especially membranes).

Challenges in operating ZLD systems — such as high energy costs, availability of consumables, and trained personnel to operate the systems — and ways to dispose and reuse sludge should be addressed from the planning and design stage. ZLD systems are expensive to operate due to the high cost of consumables and energy. For sectors such as textile industries, which are relatively less energy intensive but associated with high effluent discharge, 50 percent of power consumed by the unit can be spent for the operation of a ZLD plant (CEE India 2016). This subsequently drives up the overall production cost.

Operating ZLD plants requires the availability of consumables/additives such as water-conditioning polymers. Also, membranes should be available in the domestic market so that park operators can maintain ZLD systems. In markets where ZLD implementation has been low, spare parts may not be readily available. Considering the complex nature of this technology, the availability of skilled and experienced labor is also a key requirement for seamless operations. In addition, without cost-effective ways to dispose or reuse sludge, the ZLD system may not be economically viable. Therefore, sludge disposal and reuse methods need to be identified from the planning and design stage.

Alternate uses of sludge can be explored like waste-to-energy, as a by-product for construction materials, and as an alternative fuel for clinker manufacturing. Extraction of useful salts is another way of generating revenue and contributing to material circularity. For example, sodium sulphate, a commonly dissolved salt in industrial wastewater, has a wide range of applications in detergent, paper, tanning, and manufacturing apart from use as an adhesive, sealant chemical, bleaching agent, propellant, and blowing agent (NCBI n.d.).

Economics of the technology and financing mechanisms

A ZLD system is capital-intensive, although its cost can vary depending on the composition of incoming wastewater. The cost of establishing a ZLD system—including equipment, engineering, design, installation, and commissioning—depends primarily on the amount of liquid to be handled by the system, that is, the flow rate. Typically, ZLD systems can reach up to $25–$50 million for a flow rate of 7,000–14,000 m^3/day and $0.25–$2 million for smaller systems with flow rate of 1.5–108 m^3/day (SAMCO 2017b). Sixty to seventy percent of this CAPEX is required for establishing evaporation/crystallization processes, while the remaining 30–40 percent accounts for installing pretreatment and conditioning units and RO, with RO having a significantly larger share among the two.

The operating costs of ZLD plants can be excessively high depending on the chemistry of the feed, flow, and method of operation. If ZLD plants generate solids for disposal in a landfill after appropriate treatment, the cost of operation can be as high as $2.2–$2.3/m^3—depending on the constituents of the discharge and prevalent norms for its disposal in a region. However, if an alternate use for the discharge or sludge is identified or alternate cost-efficient methods of disposal are utilized, the OPEX can fall to $0.26–$0.33/m^3 in the best-case scenario (Marlett 2018).

Despite the high costs of the technology, however, the return on investment can be favorable, especially in water-scarce locations, if financial support and the right business models are in place. In water-scarce locations, prices of water supply are expected to be significantly high and water supply services may not be reliable. The high costs associated with limited and unreliable water supply can justify capital-intensive ZLD investments.

Key enablers

As with other technologies, various policy measures can help park operators address the challenges of adopting ZLD systems. **National or local governments can drive the uptake of ZLD technologies in the industrial sector through policy mandates.** For example, the Central Pollution Control Board of India, in 2015, issued directives to nine states along the river Ganga to enforce the installation of a ZLD system in five polluting industries (CPCB 2016).

In an extreme case, the Madras High Court ordered the closure of 743 units of the Tirupur industrial clusters in Tamil Nadu unless ZLD technologies were implemented. While the order eventually led to the closure of some plants, nearly 600 units installed a ZLD system to avoid closure (DownToEarth 2018). The installation of ZLD units in individual manufacturing units is generally slow due to high capital costs, which pushes up the cost of production by up to 30 percent (DownToEarth 2011). Application of ZLD in industrial parks provides a higher probability of uptake, since capital costs are borne by the park authority and individual units pay only operating charges.

Governments can also help create markets for ZLD technologies and provide opportunities for park operators to create innovative business models. In India, with technical and financial support from the World Bank Group, the Maharashtra Water Resources and Regulatory Authority is planning to implement a unique market mechanism to promote industrial wastewater recycling through a trading platform that targets 20 large industries, industrial parks, and municipalities. As per this mechanism, called “Tradable Wastewater Reuse Certificates,” each industry will be given freshwater allocation and will be mandated to recycle a certain percentage of the same. Industries with a recycling rate greater than their allocated resources mandate will be eligible to convert the excess into a certificate and trade with others who fall short of their recycling thresholds (World Bank Group n.d.b).

Governments can also leverage private finance through PPPs and help stimulate investment in ZLD technologies. The Tamil Nadu Water Investment Company provides an example of such a partnership. It is a joint venture between the State Government of Tamil Nadu and Infrastructure Leasing and Financial Services (IL&FS), a private sector financial services firm, which established nine textile-dyeing ZLD units in the Tirupur textile industries cluster. With a combined capacity of 53 million liters per day, these plants mitigated pollution of the Noyyal River, a major water source for local villages and farmers (IL&FS n.d.).

Governments can provide support to create standards and markets for reusing sludge (i.e., solid by-products from water treatment processes) generated from ZLD systems and other wastewater treatment facilities. Alternate uses or selling of treated sludge[21] can provide additional revenue sources and help park operators cover the high O&M costs of ZLD systems. Treated sludge generated from ZLD systems can be reused as input materials for production processes for various industry sectors and fertilizers, and as alternative fuels for other industries such as cement manufacturing (see also box 3.9 in chapter 3 for biogas production from sludge).

BOX 4.3

Zero liquid discharge technology in Hawassa Industrial Park, Ethiopia

Overview

Location: Hawassa, Ethiopia

Number of companies: 24

Sector distribution: Apparel and textile

Number of employees: 60,000

Area: 130 hectares (total); 30 hectares (factory shed—total 37 sheds)

Year of establishment: 2015

Economic significance: At full capacity, expected to generate $1 billion export value

Background

Hawassa Industrial Park is the largest textile and garment and its first zero-emissions industrial park in Africa. The Ethiopian government is trying to develop Hawassa Industrial Park into Africa's first sustainable industrial park with state-of-the-art infrastructure and operational practices. The park sources power from a renewable hydroelectric power plant and has a centralized zero liquid discharge (ZLD) water treatment system.

Motivation

Textile industries can contribute to surface water deterioration if there are no adequate treatment measures in place. Therefore, there were concerns about effluent discharge from Hawassa Industrial Park to the protected Lake Hawassa and Tikur-Wuha River. Furthermore, Ethiopia faces a water scarcity problem. Variability in rainfall patterns and distribution, exacerbated by extreme climatic events, has thrust many regions of the country, including Hawassa, into conditions of extreme water scarcity. These challenges motivated the park authority to identify circular economy solutions such as the adoption of the ZLD system.

Circular economy solutions and technologies

The ZLD system is implemented to facilitate circulation of 100 percent treated wastewater in the industrial park with minimal loss through open tanks and sludge. The system entails primary, secondary, and tertiary treatment (figure B4.3.1). The first two stages apply physical and biological treatment steps to remove suspended solids. The treated wastewater is sent to the final stage for further treatment, where micro suspended solids and total dissolved solids are removed. The water from the tertiary treatment is stored before it is pumped back to factories. If the wastewater is not of an adequate quality, it is sent back to the inlet. Rejected water from tertiary treatment is circled back to the evaporation section where concentrated salts are produced and the remaining steam is condensed and sent back to the system.

Economics

For every $1 invested in water, there is an economic return of $5–$13, which was feasible in part with government support (IPDC n.d.b).

Results

The introduction of the ZLD system helps avoid 8,000 m^3 of freshwater consumption on a daily basis.

Lessons learned for park operators

Adoption of the ZLD technology helps integrate the circular economy approach to water usage in industrial parks by designing waste out. To be economically viable, an additional system or strategies for utilizing sludge should also be put in place instead of disposing the entire volume of sludge. As an alternative to disposal, ZLD sludge can be used for the manufacturing of construction materials such as bricks and cement, although the physiochemical characteristics and suitability of the generated sludge should be assessed for the potential application.

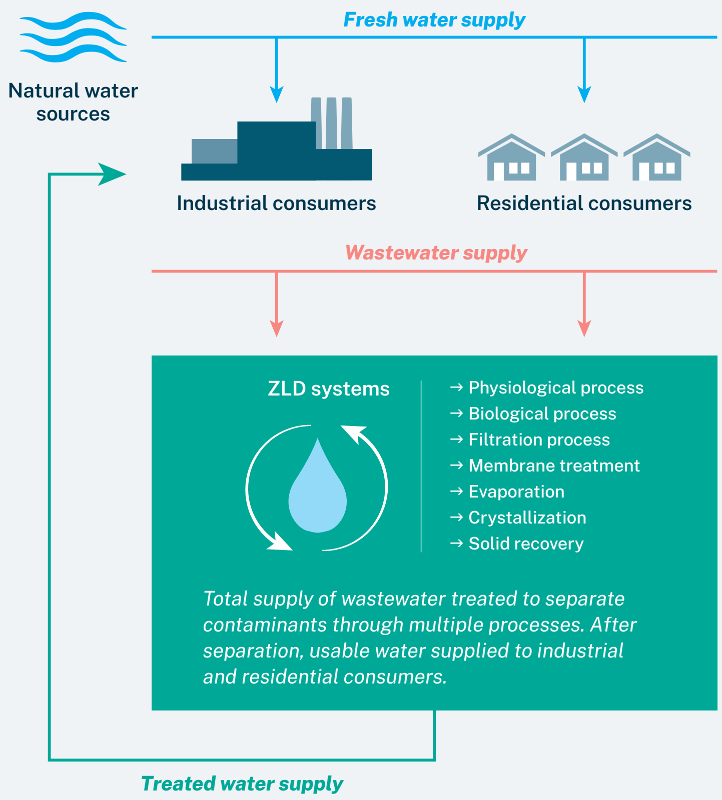
Applicability in developing countries: High

Strengths: Applicable in textile industries with high rates of water consumption. Despite the high cost, it can be financially viable in areas where freshwater availability is sparse or the cost of water is high.

Weakness: High cost of installation and operation.

Required enablers: As exemplified in the case of India, a regulatory push coupled with strict actions to stem noncompliance can help improve uptake of the technology. In order to prevent environmental degradation, local government agencies need to provide guidance to park operators on potential uses of ZLD sludge and related business opportunities by reviewing and disseminating global best practices. Government agencies can also provide technical support in implementing ZLD systems and assessing potential uses of sludge, along with disseminating market-related information on technology costs and locally available suppliers. Additionally, government agencies can explore partnership opportunities to infuse private sector financing to strengthen ZLD penetration, apart from providing financial support through subsidies or tax rebates.

FIGURE B4.3.1 • Schematic of the ZLD system implemented in Hawassa Industrial Park



Source: ZLD Ethiopia: http://www.zldethiopia.com/.

Source: Zhang et al. 2018; IPDC n.d.a; EIC n.d.

4.3.3 • Heavy and valuable metal removal/recovery technologies

Heavy and valuable metal recovery technologies are another set of technologies that park operators and tenant firms can explore in treating wastewater and increasing an additional source of revenues. Heavy metal ions are nonbiodegradable and have the potential to accumulate in the natural ecosystem if not removed. They can cause serious environmental pollution and health risks. In many countries, therefore, heavy metal concentrations in effluents at discharge points are restricted. In response to these requirements, various new technologies to minimize or recover heavy and valuable metals from wastewater streams are introduced (table 4.3). If they can be recovered and reused in production processes effectively, they can bring additional economic value, and environmental health risks can be reduced.

TABLE 4.3 • Types of heavy and valuable metal removal/recovery technologies

Chemical precipitation	Ion exchange	Solvent extraction	Adsorption
Description			
Dissolved metals are converted to an insoluble form by using precipitant (Sharma et al. 2019)	Metals present in wastewater are removed by utilizing ion exchange resin (Fluence Corporation 2016)	Metals in water are removed by adding another chemical (an extraction agent) so that the metal gets dissolved through a chemical reaction (Ola and Matsumoto 2018)	Metal particles are trapped on the surface of specific solids (adsorbent) when wastewater is passed over it (Renu and Singh 2017)
Advantages			
» Simple » Inexpensive » Effective for rare metal removal from wastewater	» Simple » Inexpensive » Effective for rare metal removal from wastewater » Selective separation of metal is possible » High regeneration of materials	» Effective extraction for wide range of metals » Selective separation of metal is possible	» Superior to other techniques in terms of initial cost, flexibility, and simplicity of design; ease of operation; and insensitivity to heavy metal ions (Hui and Guo 2012) » Capable of removing a broad range of dissolved heavy metal ions
Disadvantages			
» Large amounts of sludge production (requires additional treatment and increased cost of sludge disposal) » Extraction process is slower than others » High chemical requirement for an acceptable level of metal discharge (Farooq et al. 2010)	» Large amounts of sludge production (requires additional treatment and increased cost of sludge disposal) » Extraction process is slower than others » High chemical requirement for an acceptable level of metal discharge	» Not applicable for wastewater with low metal ion concentration » Time consuming » Labor-intensive procedures requiring large volume of solvent	N/A

For successful implementation of wastewater metal recovery technologies, market-related factors as well as technical design parameters need to be considered. These include:

» Volume of wastewater with metal content generated from waste stream;
» Available firms within or nearby industrial parks having market demand for extracted metals;
» Availability of skilled personnel for O&M of facility; and
» Availability of the metal recovery technology in local markets.

Park operators should also develop ways to safely dispose sludge. Sludge generated after the metal recovery process may contain hazardous materials, and there is limited opportunity to reuse this type of sludge. A large amount of sludge production during the heavy metal recovery process requires additional treatment and proper disposal, which can increase costs.

Economics of the technology and financing mechanisms

The cost of each metal removal and recovery technology is dependent on technical parameters including the composition and quantity of the contaminants present in the incoming wastewater. For example, the cost of chemical precipitation depends on the type and quantity of reagent to be used, which in turn depends on the type and concentration of metal present in the wastewater. For an indicative estimation of costs involved — a system designed for the extraction of chromium (Cr) and molybdenum (Mo) metals with wastewater flow of 3 m^3/hour will incur a capital cost of approximately $635,000 and an annual operating cost of $43,000 (emis 2010).

Key enablers

Identifying additional revenue generation opportunities can help cover the investment and operating costs, and facilitate the recovery of heavy metal using the various technologies indicated above. Additional revenue streams can be generated through symbiotic use of extracted metals. Industrial parks that host firms with metal finishing processes can tap into this technology at utility scale to avoid a potential decrease in CETP treatment performance and increase the economic value of recovered/recycled metals. The recovered/recycled metals can be reused and commercialized via symbiotic relationships across different sectors as demonstrated in several Chinese industrial parks (see box 4.4).

For example, in China's Huizhou industrial park, which is dominated by the electroplating industry, ultrasonic technology was introduced to recover metal from the wastewater sludge. The wastewater sludge contains high heavy metal concentrations (particularly copper) as a result of a large number of electroplating industries operating within the park. Ultrasonic technology helped the park recover metal from the wastewater sludge, which contains 3–5 percent of copper and 4–4.5 percent of iron. With the application of ultrasonic technology, 95–98 percent of dissolved copper and 97–99 percent of dissolved iron could be recovered (Xie et al. 2009). Similarly, a recycling process using solvent extraction technology was established to recover copper from wastewater in the Suzhou Eco-industrial Park of China. In the Huayuan electroplating zone, the metal recovery technology helped recycle 60 percent of wastewater and recover heavy metals — such as nickel, chromium, copper, and zinc — worth nearly $3 million annually (Li and Liu 2018).

BOX 4.4

Heavy and valuable metal recovery technology in Tianjin Industrial Park, China

Overview

Location: Tianjin City, China

Number of companies: 900+

Sector distribution: automobiles, electronics, biotechnology, food and beverage, equipment manufacturing, among others

Area: 40,000 hectares

Year of establishment: 1984 (recognized as an EIP in 2008)

Economic significance: As of 2015, its gross domestic product was around $44 billion, which accounted for 17.6 percent of the total output of the Tianjin region

Background

The Tianjin Economic-Technological Development Area (TEDA) was among China's first batch of national economic and technological development zones. Since 1997, when the Ministry of Commerce started a comprehensive appraisal of all national-level development zones, it has topped the list. Rated as "China's Most Dynamic Region" by the United Nations Industrial Development Organization, 10 industrial parks operate within the TEDA zone with firms operating in multiple sectors.

FIGURE B4.4.1 • Example of electroplating in industries

Photo credit: Lakeview Images.

Motivation

Electroplating is a finishing process for coating metal objects and is widely used in automotive, electronics, and aerospace manufacturing. It is known as one of the most polluting processes due to the complexity of the heavy metal and toxic content in its wastewater effluents. The effluent, which has a high dissolved-solid content, is both alkaline and acidic as the result of the painting processes and metals used for coating.

Circular economy solution and technologies

In TEDA, an electroplating wastewater treatment system is operated through the combination of a centralized effluent plant (CETP) and mobile units. The mobile treatment vehicles have a capacity to treat 1,000 m^3/day wastewater from post plating rinse water baths, and include 10 sets of ion exchange units along with various other equipment such as fiber filter cartridges, activated carbon, cation, anion, mixed ion exchange columns, water pumps, and air compressors. Wastewater is first treated in situ by mobile units, which results in deposits on ion exchange resins. These deposits are sent to the centralized wastewater treatment plant, where they are further refined to extract metals that can be reused in the source electroplating plants operating in the industrial parks.

The mobile treatment system, effectively combined with a CETP, helped TEDA reduce initial investment cost by 36 percent and operational expenses by 63 percent compared to a CETP design combined with a static electroplating wastewater treatment plant.

Lessons learned for park operators

As with other investments, the wastewater treatment design also requires a case-specific analysis. Park operators need to know the quality of outlet water to decide if it is economically viable to retreat the water and reuse it. Park operators can also consider using membrane technologies to treat wastewater and create an alternate revenue source by selling metals extracted from the process. The economic feasibility of this solution needs to be carefully assessed as treating highly polluted wastewater with membrane technology will increase the operational cost.

Applicability in developing countries: Medium

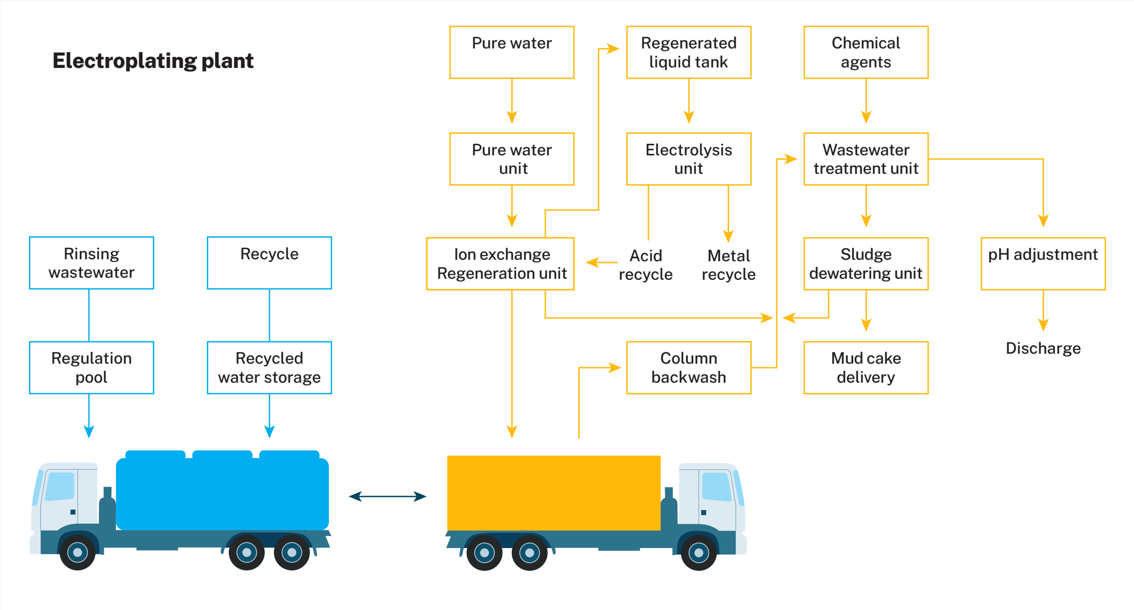
Strengths: Water that contains valuable metal content can provide an adequate amount of dissolved solids that can be sold to generate an alternate revenue stream

Weakness: High initial cost

Required enablers: Innovative system designs and business models to reduce the capital and operational costs, and establish business models exhibiting commercial use of the process output

Source: TEDA Investment Promotion Bureau n.d.; Deloitte 2017; Shi and Yu 2014; Er, Qin, and Zhang 2007.

FIGURE B4.4.1 • Example of electroplating in industries



Source: Er, Qin, and Zhang 2007.

4.4 • Key takeaways for park operators and policy recommendations

Park operators can help stimulate increased uptake of circular water supply and wastewater treatment technologies by:

» Undertaking technical assessments of water conservation possibilities in industrial parks, taking into consideration tenant firms' industrial processes to identify the quantity and characteristics of water requirements.

» Constructing a centralized system to conduct water conservation activities, thereby reducing the financial burden on individual firms. Collecting fees for services and supplying high purity water to tenant firms will help parks to ensure that returns on investment can be achieved. Park operators need to check their tenants' willingness to pay for higher fees for the centralized water supply and the quality of water required for the tenants.

» Effectively managing demand for process water and aggregating demand for wastewater reuse through balanced water tariffs. It can be supplemented with monitoring systems and continued awareness drives within industrial parks. The drives can encourage tenant firms to optimize their water consumption and reuse water wherever possible through adequate firm-level investments.

» Providing handholding to tenant firms in available technologies, market information, and available commercial financing options. To provide commercial financing options, park operators will have to negotiate favorable loan terms with prospective financing institutions.

» Various policy measures are also required at the national and local levels to mandate or incentivize wastewater treatment and reuse, increase access to finance, and raise awareness of water supply and wastewater treatment technologies among park operators and tenant firms. Examples of recommended policy interventions to encourage the adoption of circular economy solutions and technologies for water supply and wastewater treatment are listed in table 4.4.

TABLE 4.4 • Examples of recommended policy interventions to catalyze the adoption of water supply and wastewater treatment solutions and technologies in industrial parks

Area of action	Key barriers	Examples of policy interventions
Understanding water availability	» Limited information on quality and quantity of water available for extraction	**Policy development shall be preceded by:** » Comprehensive water resource assessment to identify quality and quantity of available water. » Technical studies preparing future scenarios of water availability based on existing water consumption trends. **Precedent of international cooperation in this regard;** international assistance
Water consumption and supply	» Unsustainable water consumption due to low/no cost associated with extraction and use of water » Limited incentives and policy push for park operators to use alternative sources of water	**Policies to reduce water consumption in the industry sector:** » As in Singapore, **penalty by way of higher tariffs** charged when a factory exceeds a certain limit of water usage from the public supply network. **Creation of funds** (e.g., the Water Efficiency Fund in Singapore) can also motivate industries to pursue water efficiency projects. These funds can be utilized for feasibility studies, water audits, recycling efforts, use of alternate sources of water, and communitywide water conservation programs. » **Use of alternative water sources** such as rainwater may also be incentivized and reflected in local water prices for industry to factor in water scarcity (as in Mexico). » **Set a policy target.** In China, targets were defined under the 12th five-year plan (2011–15) to reduce water consumed per unit of value-added industrial output by 30 percent by 2015. In case of noncompliance, penalties were levied or in extreme cases, closures ordered. **Policies to increase use of renewable water sources, especially rainwater, through mandates and incentives:** » In India, the municipal government mandated that buildings with a built-up area exceeding 100 m^2 were required to install a rainwater harvesting system (Ministry of Jal Shakti 2020). » In the United Kingdom, tax incentives were provided through the Enhanced Capital Allowances (ECA) scheme under which businesses can claim first-year capital allowances on certain water-efficient plant and machinery. The UK government updates an annual list of eligible water technologies, products, and the criteria for claiming. Rainwater harvesting is considered one of the eligible technologies and practices (Government of UK 2012).
Wastewater treatment	» Noncompliance with national and local laws, which results in limited or inadequate wastewater treatment	» Countries with significant industrial activities have regulations/rules stipulating the pollutant level for wastewater. » **Policy actions that ensure compliance with environmental regulations** such as levies on unlawful discharge of wastewater and periodic/random auditing of industrial facilities
Water reuse/recycle	» Limited policy push or incentives for water reuse and recycling	» **Policies to mandate water reuse/recycling** wastewater for non-potable uses including process water usage. » **Financial incentives** such as reduced taxes or tax exemptions can encourage firms and park operators to adopt water reuse/recycling technologies.
International cooperation	» Limited availability of technical expertise in local/regional market » Cost implications of importing technology from international players	» **Leverage international funding and technical expertise** to develop competencies in implementing wastewater technologies. For example, the World Bank Group (n.d.c) has established the 2030 Water Resources Group which has industrial water use reduction and reuse as a key focus area. It identifies public-private partnership opportunities, bringing in best-practice technological solutions and financing models, and implementing demand-side efficiency measures as well as helping to develop tariff structures for industrial water use.

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Endnotes

1. Water stress is the ratio of water withdrawals to mean available blue water (i.e., water from underground and surface sources that is fit for human consumption). It occurs when demand exceeds the available amount or poor quality restricts water use and causes the deterioration of freshwater quantity (by aquifer overexploitation, dry rivers, etc.) and quality (by eutrophication, organic matter pollution, saline intrusion, etc.).
2. The hydraulic load is the flow of wastewater to a WWTP in a certain time span, that is, the amount of wastewater the plant can process. Its common unit is million liters per day (MLD). It depends on the wastewater volume present at the source and the volume to be treated in a particular time period.
3. The pollution load is the amount of pollutants added to an incoming water stream, resulting in the generation of wastewater in the outgoing stream of a water consuming process. It determines the technology required to treat wastewater.
4. The biological oxygen demand (i.e., the amount of oxygen required for bacteria to degrade the organic compounds present in water/wastewater), chemical oxygen demand (i.e., the total chemicals in the water), total dissolved solids, and suspended solids of industrial wastewater can be much higher than those of municipal wastewater.
5. Converted to US dollars ($) at the 2020 annual average exchange rate of $1 = ₹ 74.1, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates. ₹ = Indian Rupee.
6. Underground rainwater harvesting systems account for 70 percent of total installation costs, while above ground costs account for only 45 percent of total costs (Minnesota Pollution Control Agency 2017).
7. Generally, countries do not apply a fixed rate across regions for water. The rate is identified based on the supply/demand scenario as well as the cost of water treatment, piping, and other ancillary works required to bring water from the source to the tap. The wide variation in water costs is exemplified in the case of Turkey, where it varies between $0.35 and $2.32 per cubic meter ($m^3$) across 331 organized industrial zones and tenant firms. (conversion based on the exchange rate of May 31, 2020: $1 = Turkish lira/TRY 0.147).
8. For regions in high latitudes and moist midlatitudes, precipitation is expected to increase. Many midlatitude and subtropical arid and semi-arid regions will likely experience less precipitation (IPCC 2014).
9. This organized industrial zone (OIZ) hosts 334 tenant firms producing food, textiles, basic metal, furniture, and motor vehicles.
10. $1 = TRY 3.52 based on the June 2017 foreign exchange rate; water tariff is TRY 15.83 + value added tax per m^3.
11. The Middle East and North Africa (MENA) is the world's most water-stressed region. Individual countries surrounding MENA, such as Greece and Spain, and other countries such as Singapore, India, Chile, and Mexico also rank high for water stress levels. For further studies, see the water stress country rankings of the World Resources Institute (WRI 2015) and World Bank (2014–15).
12. There are typically four types of water based on salinity — freshwater (<0.05 percent), brackish water (0.05–3 percent), saline water (3–5 percent), brine (>5 percent). Typically, seawater is categorized as saline water, while brine is found only in special areas like brine pools (localized areas within oceans with higher salinity than the surrounding ocean water).
13. Salinity is the amount of dissolved salts in water, measured in parts per thousand or percentage of total weight.
14. An estuary is a partially enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea.
15. This includes specific seas or lakes that have brackish water like the Baltic Sea, Caspian Sea, Hudson Bay, and Black Sea, among others.
16. The cost of desalination plants decreased by up to 20 percent between 2010 and 2017, depending on geographical location (Advisian 2018).
17. For instance, an alternate hybrid system, combining solar photovoltaic and wind power, is in the research and development stage and may prove viable in the future (Ahmed, Hashaikeh, and Hilal 2019).
18. These include management, operation, and maintenance contracts; concessions; design-build-operate and build-operate-transfer agreements; lease and affermage contracts; and raw and treated water bulk supply agreements. For further reading on each PPP model, see World Bank Group (2019).
19. These include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.
20. A key concept related to organic matter in wastewater is biological oxygen demand (BOD). BOD is the oxygen required for decomposition of organic matter by aerobic organisms like bacteria. The higher the content of organic matter, the higher the BOD, which lowers the availability of oxygen for aquatic organisms. Hence organic matter content in wastewater needs to be reduced through treatment processes.
21. By-products generated from treatment processes contain water that is removed by compression to produce a solid cake. The cake is either disposed in a landfill or utilized in alternate applications.

5 Material and waste heat recovery

5.1 • Overview

Eco-industrial parks (EIPs), especially those that involve mixed uses, encompass diverse industry sectors and processes. Various types of materials, in various forms — solid, liquid, and gaseous — can be recovered from or during these processes. These materials can then be used as raw inputs for other uses, whether by tenant firms or entities located outside the park. These industrial processes may be linked systematically so that materials and energy can be recovered, processed, exchanged, and reused effectively for the purpose of increasing productivity and cost savings.

These systematic linkages, which create mutual interdependencies between or among firms for their higher production efficiency and business profits, are referred to as industrial symbiosis networks. Industrial symbiosis, as commonly defined, involves engaging traditionally separate industries in a collective approach to sharpen their competitive advantage (UN 2015). It involves the physical exchange of materials, energy, water, and by-products (Chertow 2000). Industrial symbiosis creates an interconnected network among firms and industrial stakeholders that strives to mimic the functioning of an ecological system, within which energy and materials cycle continually with minimal waste generated from the system. This symbiotic relationship makes participating firms highly interlinked and dependent on one another to the extent that the operation of one firm affects all others involved in the same system.

In an EIP, industrial symbiosis solutions may be of two types: **those that interlink the functioning of the entire park to individual firms (the zone-firm model), and those that connect firms to other firms (the firm-to-firm model).** For instance, parks can recover waste heat from boilers to improve their common infrastructure and shared services, and tenant firms can depend on the energy and resources generated from this common infrastructure. Or networks can be created to foster the recovery, exchange, and reuse of materials and energy among firms themselves. Through both types of interventions, diverse industrial stakeholders can mutually benefit by co-creating and adding value, reducing production costs, and mitigating their environmental and carbon footprints (UNIDO, World Bank Group, GIZ, and Ministry of Trade, Industry and Energy 2018).

There are clear economic motivations for both park operators and tenant firms to create (or join) industrial symbiosis networks. For example, where a park's common infrastructure is retrofitted or designed to create such a network, this helps reduce the investment and operational costs of its tenant firms — costs associated with purchasing raw materials, treating wastewater, managing waste, or reducing greenhouse gas (GHG) emissions. Through centralized steam generation or carbon dioxide (CO_2) recovery systems, park operators can not only help tenant firms lower their operational costs but also create new revenue streams that can cover the investment and operational costs associated with industrial symbiosis. In the firm-to-firm model of industrial symbiosis, firms that recover and sell materials ("sending firms") can create revenue streams from their investments while "receiving firms" can increase production and utility cost savings. In this way, the receiving firms, especially those with inefficient production systems either due to the nature of production processes or outdated facilities and equipment, can also reduce the additional investment costs of mitigating environmental and carbon footprints. Industrial parks provide a good opportunity to establish these mutually beneficial relationships at scale because companies are located close to one another, and materials and by-products are relatively easy to obtain and exchange.

Industrial symbiosis solutions and technologies need to be case specific and reflect conditions on the ground. The materials recovered from various industrial processes have their own unique forms, types, and characteristics. Therefore, they should be tailored to the industry sectors, types of common infrastructure, and services available on site, and specific needs and production processes of the tenant firms. Solutions require certain quantities, technologies, and returns on investment. Especially in the firm-to-firm model, they also require trust among partners to be able to sustain reciprocal systems of production, exchange, and reuse.

This section provides a methodological approach, business strategies, and examples of industrial symbiosis technologies that park operators can adopt in identifying and creating economically viable industrial symbiosis opportunities. An assessment of material/waste flows and demand is an essential first step and, along with other traditional services, can be supported by EIP operators seeking to foster firm-to-firm industrial symbiosis solutions. To that end, this chapter also outlines the types of assessments that can be conducted at the park level to identify the most suitable industrial symbiosis technologies, focusing on the technical and financial evaluation of investment opportunities.

Key observations from data collected from surveyed EIPs

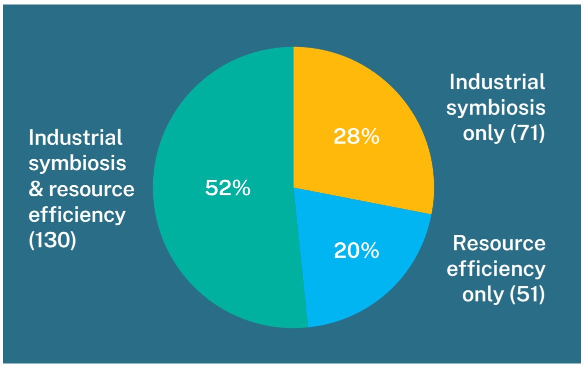
Efforts to enhance material circularity and reuse of waste are booming around the world, promoted at the level of the nation (e.g., the United Kingdom's National Industrial Symbiosis Programme, China's National Demonstration Eco-Industrial Park Program), region (e.g., Sweden's Cleantech Östergötland), and industrial park (e.g., Denmark's Kalundborg). Such programs have been able to achieve considerable success. For example, the National Industrial Symbiosis Programme has:

- Diverted 47 million tons of industrial waste from landfills
- Generated $0.77 billion in new sales
- Reduced carbon emissions by 42 million tons
- Reused 1.8 million tons of hazardous waste
- Created and safeguarded over 10,000 jobs
- Cut costs by £1 billion (by reducing disposal, storage, transport, and purchasing costs)
- Saved 60 million tons of virgin material
- Saved 73 million tons of industrial water (International Synergies Limited n.d.)

Similarly, in the Republic of Korea, industrial symbiosis strategies have been implemented in industrial parks as part of a national program for EIPs that involved 1,831 companies and commercialized 235 projects (KITECH-KNPC 2020).

Industrial symbiosis projects are implemented in many EIPs both at the park level and between firms. According to a World Bank (2020) survey, 57.5 percent (or 252) of surveyed industrial parks have industrial symbiosis or resource efficiency measures in place, either solo or in combination. Forty-eight percent of the surveyed industrial parks implemented interventions either focused on resource efficiency (green infrastructure at the park level) or industrial symbiosis (synergies established among tenant firms) (figure 5.1), while 52 percent invested in both resource efficiency and industrial symbiosis technologies.

FIGURE 5.1 • Distribution of resource efficiency and industrial symbiosis investments



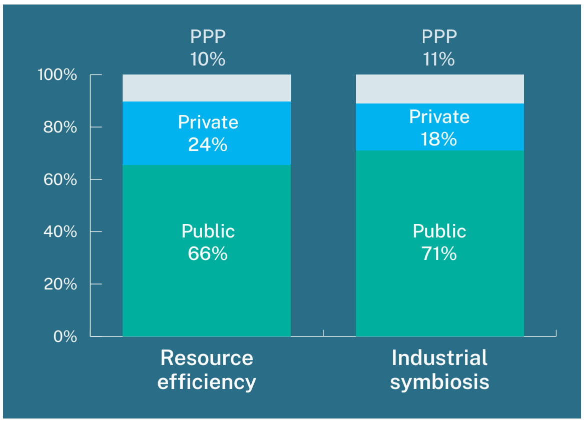
Source: World Bank 2020.

Note: Total number of EIPs with either resource efficiency or industrial symbiosis, or both measures in place = 252 (57.5 percent of the total EIPs). Total number of surveyed EIPs = 438.

Public support for industrial symbiosis investments is prevalent. The global EIP data highlight that industrial symbiosis investments are still largely made by public entities. Of the parks that have invested in measures to improve resource efficiency, 65.5 percent are publicly owned and operated, 24.1 percent are privately owned, and 10 percent are private-public partnerships (figure 5.2). This finding indicates that, as with other technologies adopted in EIPs, governmental support is still crucial for the increased adoption of industrial symbiosis and resource efficiency practices and technologies, and that the business case for undertaking such initiatives is yet to be widely recognized by private sector stakeholders.

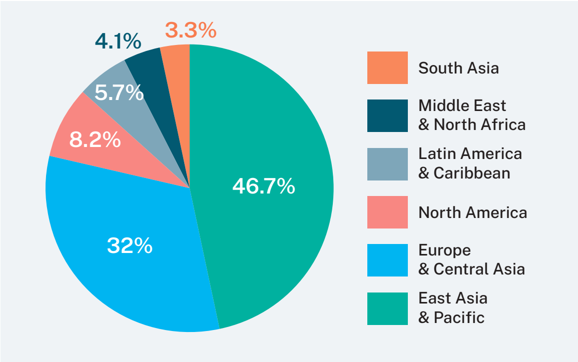
Resource efficiency and industrial symbiosis measures are more widely implemented in industrial parks operating in Europe and Central Asia (ECA) and the East Asia and Pacific (EAP) regions (figure 5.3). The data highlight potential opportunities for improving resource efficiency and industrial symbiosis in regions such as Latin America and Caribbean, the Middle East and North Africa, Sub-Saharan Africa, and South Asia. These regions have emerged as global trade and logistics hubs and centers for minor assembly, packaging, and/or redistribution facilities due to changes in the global market, and sourcing and manufacturing locations (Supply Chain Management Review 2015).

FIGURE 5.2 • Type of ownership of surveyed industrial parks investing in industrial symbiosis



Source: World Bank 2020.
Note: PPP = public-private partnership.

FIGURE 5.3 • Geographical distribution of surveyed industrial parks investing in industrial symbiosis



Source: World Bank 2020.

Industrial parks provide important opportunities for firms to participate in global value chains (GVCs). Therefore, resource efficiency and industrial symbiosis interventions in industrial parks operating or planned in various regions can help scale up the circular economy approach across GVCs. It is necessary to strengthen park operators and firms' knowledge and capacity related to industrial symbiosis and resource efficiency projects, and introduce various benchmarks, financing mechanisms, business models, and tools.

5.2 • Industrial symbiosis technologies

Establishing an industrial symbiosis network is an important component of an EIP and a building block for mainstreaming circular economy principles beyond industrial parks and across value chains (UNIDO, World Bank Group, GIZ, and Ministry of Trade, Industry and Energy 2018). The examples of industrial symbiosis outlined in table 5.1 and table 5.2 highlight that:

» **Park operators have motivations to invest in industrial symbiosis infrastructure and services not just from environmental but also economic and social perspectives.** Recovered materials and by-products can become a source of revenue for industrial parks and firms. Identifying the potential needs of stakeholders is the first step in the design and implementation of an industrial symbiosis project.

» **Symbiotic relationships can extend beyond the geographical boundaries of industrial parks** to include surrounding urban areas and industries. Recovered materials can be sold as sustainable products, becoming a source of revenue for the industrial park.

TABLE 5.1 • Motivations to invest in industrial symbiosis infrastructure in industrial parks

Industrial parks	Main externalities	Stakeholders affected	Motivation	Industrial symbiosis projects	Benefits
Gladstone, Australia	Extraction and consumption of water from local reserves during drought seasons	Communities around the industrial park	Alumina production using water from local sources	Constructing an 8.5 kilometer pipeline for utilizing secondary effluents sourced from the city's sewage treatment plant for mud washing	» Alumina refinery operational even during drought » Cost savings by avoiding installation of tertiary treatment at the city's sewage treatment plant
Kalundborg, Denmark	Resource waste during refinery process	Communities around the industrial park	To reduce the amount of gases lost during the flaring process[a]	Pipelines convey flare gases to a nearby power plant where it is used as supplementary fuel	» Reduction in operational expenses and greenhouse gas emissions associated with power plant operation » Alternate revenue source for refinery
Kwinana, Australia	Production of contaminated acid water	Communities around the industrial park	Diluted hydrochloric acid produced by manufacturer of titanium dioxide pigment[b]	Hydrochloric acid reuse	» Revenue from sale, avoided treatment costs, water source conservation

Source: Jacobsen 2006; van Beers et al. 2007.

Note:

a The flaring process involves combustion of unwanted volatile gases generated during oil and gas production for pressure relief. It helps prevent the risk of explosions and avoids venting of the dangerous gases directly to the environment.

b Titanium dioxide, which is often used to impart whiteness to food products, cosmetics, and personal care items, is extracted from minerals through treatment with the concentrated form of a chemical, hydrochloric acid. After extraction of titanium dioxide, the diluted acid is typically disposed of.

STP = sewage treatment plant; GHG = greenhouse gas.

In Korea, more than 450 feasibility studies were conducted across 105 industrial parks in the country as part of the national EIP program. Out of these, 247 feasibility assessments (54.8 percent) were actually commercialized. In total, 1,865 companies participated in identifying industrial symbiosis opportunities to date, generating around $44.3 million worth of economic gains every year (table 5.2).

TABLE 5.2 • Korea's industrial symbiosis projects and their accumulated benefits (2005–20)

Type of benefit	Parameters	Value	Unit
Economic	Operational cost savings	264.3	$ million
	Revenue increase	401.3	$ million
	Total economic gains	665	$ million
Environmental	Waste reduction	1,691,683	ton/year
	Wastewater reduction	36,791,709	ton/year
	Energy savings	399,151	ton/year
	SOx and NOx reduction	156,659	ton/year
	GHG emission reduction	2,101,257	ton CO_2-eq/year
Social	Investment generated	763	$ million
	Job creation	1,027	No. of person

Source: Park et al. 2018; KITECH-KNPC 2020.
Note: GHG = greenhouse gas; NOx = nitrous oxides; SOx = sulfur oxides.

Despite these tangible benefits demonstrated in various cases, barriers still exist to implementing industrial symbiosis projects, especially those of the firm-to-firm model. Firms may be reluctant to establish symbiotic relationships due to lack of trust, and may hesitate to share confidential data that reveal details of their production processes, source materials, and by-products with other companies. Infrastructure investment is often required for enabling symbiotic relationships such as exchanging waste heat, and, in this case, the companies may feel uncertain about the profitability of the investments and the associated costs and risks, partly due to a lack of understanding of industrial symbiosis mechanisms and their economic benefits. Additionally, if companies can source raw materials at a cheaper price than that of recovered materials or by-products, they will not be motivated to invest in creating processes or facilities required for recovery and reuse.

But there are also factors that help establish and scale up symbiotic relationships. For example, the presence of diverse industry sectors opens up a range of opportunities because various types of materials and by-products can be recovered from these industries. Where **a large number of companies** undertake the same type of economic activity, this helps to create a more constant flow of useful by-products and can lead to infrastructure sharing and joint provisioning of services. **Geographical proximity** between potential participants can lower transportation and environmental costs, and helps secure the financial viability of the symbiotic relationship. It is also helpful in terms of creating new symbiotic connections if park operators have **entities to support them to facilitate industrial symbiosis projects on site.** These entities can provide training for companies, facilitate exchange of information, foster cooperation and trust between companies, and help identify possible symbiotic relationships through negotiations.

These barriers and drivers for industrial symbiosis are case specific, and can affect the type of interventions implemented in industrial parks. While establishing firm-to-firm symbiotic relationships can be challenging, some factors can make the zone-firm model easier to implement. Capacity for developing centralized infrastructure can help in effectively bringing down costs and address perceived risks involved in initiating firm-to-firm symbiosis projects. Use of centralized systems can also help park operators act as facilitators in establishing potential symbiotic relationships.

5.3 • Technologies enabling material and energy recovery processes

A wide range of technologies can be implemented to achieve industrial symbiosis. Table 5.3 describes potential strategies for recovering material and energy at the industrial park level; all can be implemented as part of industrial symbiosis solutions. The available technologies listed in the table have been identified by analyzing the data on the 438 surveyed EIPs and the results have been integrated with further assessments of best practices in energy/material/organic recovery. The table can be used as a reference for identifying the most advanced technologies to process various resources and wastes.

TABLE 5.3 • Processes and technologies required to recover different resources

Resource	Source	Type of intervention	Process	Available technologies and facilities
Water	Cooling water, process water, treated wastewater	Material recovery	Direct use or reuse without further treatment	Wastewater treatment*
Energy	Waste heat from boilers and kilns used in cement production	Energy recovery	Shared use of energy infrastructure, cogeneration, and/or recovery of waste heat from steam and power generation	Organic Rankine Cycle
Nonprocess waste	Packaging materials, machinery components, waste generated while performing routine or emergency maintenance, household waste	Material recovery/ energy recovery	Separation and recovery to reclaim specific material in the by-product/waste stream (including organic waste)	Waste sorting and recovery
			Processing to produce a different useful product	Pyrolysis
Other	Wastewater,* CO_2, or hazardous waste	Material recovery	Service or utility sharing for collective treatment, disposal, or recovery	CO_2 recovery

Source: Van Berkel, Bossilkov, and Corder 2005.
Note: *See chapter 4 for the types of technologies used in wastewater treatment and recovery of metals.

While the technologies listed in table 5.3 can be potentially used for both firm-to-firm and zone-to-firm interventions, their application in the second of the two models is more prevalent. In case of firm-to-firm applications, there is an inherent technical constraint in terms of the quantities of by-products that can be exchanged between firms as well as the capital and operational costs, making the application of certain technologies not viable financially. Three technologies are particularly advanced and widely used — high temperature pyrolysis, CO_2 recovery, and the Organic Rankine Cycle (ORC). According to the classification of the International Energy Agency, these three technologies are at a technology readiness level (TRL) 9, which means that solutions are commercially available but require further improvement to become financially competitive (NASA 2012; IEA 2020).

5.3.1 • High Temperature Pyrolysis

In industrial parks, organic waste and sludge can be collected and used to produce biofuel or biogas in a pyrolysis plant. Pyrolysis technology decomposes organic materials through high-temperature thermochemical processes that do not require oxygen. Biochar, the by-product of this process, can be used as a soil ameliorant for both carbon sequestration and soil health benefits, providing alternative revenue-generating options for park operators. The minimum volume of organic waste and sludge that makes this process economically viable is around 3,000 tons/year or higher depending on the caloric value and humidity of the organic waste and sludge. The equivalent power capacity for this intake value is 250 kilowatts (kW), requiring capital expenditure of up to $1 million.

5.3.2 • CO_2 recovery technologies

CO_2 can be recovered from fumes coming out of boilers, biogas or biomethane production processes, captive power plants, and other combustion processes in industrial parks. It can be also recovered as a by-product from cement production, fertilizer (ammonia) production, and bio-ethanol fermenting processes. CO_2 recovery, purification, and/or liquefaction plants provide important business opportunities to reuse CO_2 in various industry sectors (table 5.4). Technical and economic assessments are required when considering operations to recover CO_2 or establish a centralized unit for potential users of CO_2 as raw material or for other applications in industrial parks. The cost of recovering CO_2 can vary from $25 per ton of carbon dioxide (tCO_2) to $300/$tCO_2$, depending on the type of processes from which extraction takes place — petrochemicals cost the least while cement, petroleum refining, iron, and steel have the highest cost (Dewar and Sudmejjer 2019).

TABLE 5.4 • Examples of value-added reuse of recovered CO_2 in various sectors

Sectors	Potential	Applications
Chemical and oil	High	Enhanced oil recovery high, enhanced gas recovery, enhanced coal bed methane recovery, stimulation/fracturing of oil and gas, urea production, polymer processing, chemicals, and fuels (methanol, methane, CO, fertilizers, and derivatives)
Food	Medium	Beverage carbonation medium, coffee decaffeination, wine production, food processing, food preservation, food packaging (modified or controlled atmosphere packaging), dry ice production, horticulture (greenhouses), refrigeration
Mineralization	Medium	Calcium and magnesium carbonate for use in cement, baking soda, CO_2 concrete curing, bauxite residue treatment (red mud)
Power	Low-Medium	Heat pumps, working medium in other CO_2 cycles
Energy crops	Medium	Algae cultivation (biomass production via photosynthesis)
Pharmaceutical	Low	Chemical synthesis, supercritical fluid extraction, product transportation
Pulp and paper	Low	pH reduction during washing
Steel	Low	Injection to metal casting low, bottom stirring agent in BOF furnaces, chilling medium, hardening sand cores and molds
Other	Low	Electronics (in printed circuit manufacture), pneumatics (working medium in hand tools and equipment), welding (shield gas), fire extinguishers, fire suspension, flavors, fragrances, blanket products, aerosol can propellant, inert gas, soda ash production for glass industry, dry gas cleaning, water treatment, refrigerant

Source: Koytsoum, Bergins, and Kakaras 2018.

5.3.3 • Organic Rankine Cycle

ORC systems are environmentally friendly systems in which low-grade heat sources can be utilized (Yamamoto et al. 2001). They are used in generating electric and thermal power, exploiting multiple sources, such as renewables (biomass, geothermal energy, solar energy), traditional fuels, and most importantly, waste heat from industrial processes, waste incinerators, engines, or gas turbines (Tian and Shu 2017). ORC systems and technologies can be applied in generating waste heat from various industry sectors such as iron and steel, nonferrous metals, cement, and glass manufacturing.

The investment costs of ORC systems vary significantly by the size of their units: the larger the size, the less expensive it becomes. The size of an ORC system depends on the electrical output of the system. Small-scale units (i.e., ORC systems with output of 5–100 kW) have an installation cost ranging from $3,000 to $4,000 per kW (Tocci et al. 2017), whereas large-scale units[1] cost nearly $1,500–$2,500 per Kw (Arvay, Muller, and Ramdeen 2011). Operation and maintenance costs range between 2 and 8 percent of this capital cost, with the lower bound applicable for higher-capacity plants and vice versa (Southon 2015). A set of ORC systems can be integrated into the common infrastructure of industrial parks so that low-grade waste heat can be reused effectively. The integration requires intra-and interplant heat exchange for the process streams (Hipólito-Valenciaa et al. 2014). The ORC system (Baleynaud et al. 2016) helps reduce the usage of external cooling and heating utilities, and hence electricity consumption.

Key considerations for implementation

The design of an industrial symbiosis project, including the choice of its technologies, is highly dependent on the types and quantities of materials available within and around parks, and to what extent they can be recovered and reused. Therefore, it is essential to undertake a structured assessment using appropriate tools.

At the initial stage, park operators can consider the following two options:

» **Recovery of source materials** (such as recyclable plastics, glass, paper, metals, effluents) that have value and be recovered and reused within the park, or sold to firms and organizations outside the park. Hazardous waste streams should be analyzed as well, since they can be processed at the firm level in a synergic way (industrial symbiosis between two or more companies) to generate new products or services.

» **Energy recovery and use** through which useable energy can be recovered from multiple production processes taking place within the industrial park (WBCSD 2018). Park operators can consider the following three main strategies for energy recovery and use:

- Energy can be generated from an ***organic component of the solid waste*** through biochemical energy recovery processes (see section 3.3.3 on renewable energy technologies). Energy can be also recovered from industrial and solid waste through high-temperature conversion processes known as “thermo-chemical energy recovery” like combustion (waste-to-energy), gasification, pyrolysis, and liquefaction. Potential gas streams also exist in industrial processes and can be recovered before flaring, as commonly seen in petrochemical industries and refineries.

- ***Waste heat exchange:*** Industrial production processes and distribution networks for conveying heated fluids like steam are the sources of waste heat in an industrial park. Utilization of this waste heat requires an assessment of the quality and quantity of waste heat, both of which depend on the temperature of the heat generation source.[2]

- ***Utilization of low-pressure waste steam:*** For industrial processes in which steam is injected under pressure, energy content decreases and pressure declines as the steam transfers its heat, leading to low-pressure steam at the outlet. The energy content of low-pressure steam is usually vented to the atmosphere and condensed in a cooling tower. This low-pressure waste steam can be compressed or boosted to a higher pressure so that it can be reused in other industrial production processes (US DOE 2014).

Park operators can conduct a preliminary assessment to identify and prioritize potential industrial symbiosis opportunities. Park operators need to assess the distribution of industry sectors, as well as the types and quantities of materials recoverable within the park. This kind of preassessment helps them understand the prospects of the material and energy recovery strategies mentioned above, and determine the need for further assessments. It can help identify more concrete opportunities and can increase the value generated from implementing industrial symbiosis projects. Table 5.5 provides an indicative list of such opportunities and the level of analysis required for implementation.

TABLE 5.5 • Types of industrial symbiosis interventions and waste assessments

Type of industrial symbiosis interventions	*Source of waste*	*Potential use*	*Analysis**
Park-to-firm industrial symbiosis	**Waste collected from tenant firms**	Segregation and use of recyclable/reusable material	Simple
	Organic solids collected from tenant firms	» Biogas generation/biofuel/biomass » Compost material	Simple
	Waste heat from captive power plants	Steam generation	Intermediate
	Waste heat from boilers	Condensate for cooling systems	Intermediate
	Gas streams from boilers or captive power plants	CO_2 recovery for use in beverage/safety equipment manufacturing units	Intermediate
	Organic effluents in STP and/or CETP	Biogas generation from secondary treatment	Intermediate
		Biogas generation from sludge	Simple
	Liquid component of incoming wastewater in STP and/or CETP	Reused treated wastewater (grey water/process water)	Simple
Firm-to-firm industrial symbiosis	**By-products and waste from industrial units**	Recycling/reuse of recoverable material for other processes/products	Complex
	Waste heat in metal or steel manufacturing plants, paper mills, or cement plants	Generation of steam and transport to end-users through steam highway	Complex
	Gas streams from flare stack	Fuel recovery for steam generation, especially for chemical companies	Intermediate

Source: Original compilation.

Note: * The level of analysis — simple, intermediate, and complex — has been categorized based on the skills and corresponding costs required for undertaking the analysis. STP = sewage treatment plant; CETP = common effluent treatment plant.

Park operators can prioritize industrial symbiosis options to maximize the reuse of outputs from existing park infrastructure. For instance, as illustrated in table 1.6, biogas and graywater may be quite readily made available if the STP or CETP is already operational. By maximizing the reuse of outputs available from common infrastructure, park operators can seek to significantly lower costs associated with implementing park-to-firm industrial symbiosis projects while increasing the circularity of resources and GHG emissions reductions within the park.

Park operators can also identify firm-to-firm symbiotic relationships based on the preliminary assessments of the type of sectors co-located in the industrial park. Park operators and firms, including both the source and receiving industries, can consider a range of possibilities for such relationships, as illustrated in table 5.6.

TABLE 5.6 • Relations between different sectors based on by-product use

Sector(s) from which material can be recovered	*Sector(s) in which recovered material can be reused*
Textile, rubber	Plastics, construction, textile, automotive, agriculture, energy, rubber
Metals, nonmetal, chemicals, construction	Construction, agriculture, infrastructure
Metals	Food, beverage, metals
Electrical/electronics	Electronics
Food	Agriculture, energy, chemical, pharmaceutical
Plastics	Plastics, construction, agriculture, electronics, automotive, textile

Source: Original compilation.
Note: Source industries are industry sectors from which materials/by-products are produced or can be recovered.

After the preliminary assessment, further, detailed assessments should be undertaken to closely examine the viability of the industrial symbiosis opportunities identified during the preliminary assessment. Park operators can collect and assess detailed information on materials, by-products, organic waste, and waste heat. This information will include the type of sectors, number of personnel, the type of product and raw materials, the amount and type of recoverable materials (including both hazardous and nonhazardous waste), physical characteristics of materials, method of storage and maintenance, recycling methods, final disposal methods and locations, the organizations responsible for waste collection, and so on. It can be particularly useful to leverage existing systems that park or infrastructure operators use to manage and monitor materials, by-products, emissions, and waste. For instance, data on the amount of discharge water and sludge coming from common infrastructure such as a CETP or STP should be already available to the park operator, if the park operator operates and manages this infrastructure.[3] Where relevant information is not known, a set of questionnaires can be developed and field assessments can be conducted.[4] Waste heat analysis can be also conducted by actively engaging in data sampling and collection processes. This will help examine specific heat losses and heat exchange efficiency, condensate temperature and flowrate, exhausted gas or fume temperature, and so on.

Material flow analysis (MFA)[5] is often used during these detailed assessments. It helps quantify material exchange and visualizes material and energy flows within an industrial park to create a database on the inputs (e.g., raw material use, water, and energy demands) and outputs (e.g., by-products and waste heat) from firms within and outside industrial parks. In addition, MFA helps analyze the composition of the used substances, assess their economic values, and facilitate a financial analysis.

Based on the data analysis mentioned above, park operators can conduct or use the feasibility studies to support partnership-building and joint investments with interested tenant firms. Potential partners in an industrial symbiosis project can perform further analysis of possible overlaps in the supply chain and also identify potential matches of outputs to needed inputs.

Park operators can also reach out to firms outside the park to facilitate the placement of by-products and recovered materials in the larger market, partnering with the symbiotic companies. One option is for park operators to create a knowledge and management exchange platform that allows firms in the park to exchange information with potential investment partners or to share services that might benefit multiple companies (common utilities, logistics, storage, recycling and disposal processes). Park operators can support the matchmaking among companies through events, technical workshops, and seminars on the potential benefits of industrial symbiosis. They can help identify underdeveloped synergies, support companies to develop potential investments and reach agreements, explore financing mechanisms, or provide common infrastructure such as interconnecting pipelines. **This "service innovation" promises to generate revenue and add value for all concerned.**

A range of digital tools and platforms are being developed to support park operators and firms in identifying industrial symbiosis opportunities and assessing their technical and economic feasibility. In France, digital technologies are used to identify potential synergies and industrial symbiosis opportunities in greenfields (box 5.1). In Korea, a digital platform is being developed to match companies with high industrial symbiosis potential. The platform is based on comprehensive firm-level data sets and allows the simulation of feasibility studies based on real-life industrial symbiosis business cases (box 5.2).

An increasing number of park operators around the world are providing supporting services. In the northern European countries, especially in Finland, Norway, and Sweden, firm-level assessments of industrial symbiosis opportunities are among the key consulting services that park operators or management entities provide their tenant firms. The role of park operators in these cases is entrepreneurial: providing an array of new services for tenant firms, they seek to facilitate investments in industrial symbiosis initiatives and decrease the capital risk in investments for infrastructure such as biogas or CO_2 recovery plants. Box 5.3 illustrates a zone-to-firm industrial symbiosis case implemented in Händelö, Sweden, where an on-site project management team at the industrial park plays a pivotal role.

BOX 5.1

Les Portes du Tarn industrial parks: Digital technologies for identifying biogas and industrial symbiosis opportunities in a greenfield EIP

In France, a range of IT tools were used in the Les Portes du Tarn park, located in Toulouse, to identify key needs of applicants, collect data, analyze inputs and output flows, and identify potential industrial symbiosis opportunities. Committed to the sustainable development of industrial parks, Portes du Tarn Park developed an initiative named the COPREI project, or the "Design of a Business Park on the Principles of Industrial Ecology." Through the COPREI project, the industrial park optimizes the management of material and energy flows for companies, while reducing the impact of activities on the environment. The tools were developed as an output of COPREI and funded by the public research institute with financial support from the French Environment and Energy Management Agency (ADEME).

EFFIE™ ("EFFiciency for Industrial Ecology") is a collaborative web application tool that helps park operators and tenants preassess input/output data flows. This tool identifies future potential substitution and mutualization synergies across materials, energy, equipment, and services. It also allows the simulation of potential industrial installation scenarios and integrates a Web GIS (geographic information system) technology to identify the "best" plot within the park for an applicant company to operate (table B5.1.1). The tool is supported by data collection on the company site, the main needs of applicants, and the main utilities, logistic services, and firm-level material input/output flows. These comprehensive tools can help monitor the environmental performance of industrial parks in real time.

EFFIE was used by the first applicant in Les Portes du Tarn—a wine production industrial company to identify two potential substitution synergies (i.e., recycling silica in bottle rinsing water and recycling rinsing water through future industrial water networks). This industrial symbiosis solution will provide process water to other tenant firms within the same industrial park at a competitive price.

Source: Belaud et al. 2019.

TABLE B5.1.1 • Features of web-based GIS tools for identifying synergies among potential tenant firms

Name of tool	*Type of tools*	*Main functions*
Actif	Web GIS	» Data storage on material flows of studied companies » Identification of synergies and geocoding
Inex	GIS	» Data storage on the material flows of studied companies » Theoretical data on the material flows of main industrial processes » Identification of synergies and geocoding using both theoretical and empirical data
Editerr	GIS	» Data storage on the material flows of studied companies » Theoretical data on the material flows of main industrial processes » Identification and geocoding of synergies, using theoretical and empirical data
EFFIE	Web GIS	» Data storage on flows of studied companies » Identification of synergies and geocoding » Identification of the "best" plot with potential industrial symbiosis for an investor/ applicant

BOX 5.2

Smart closed-loop grid system in Korea: A digital platform to identify and match industrial symbiosis opportunities

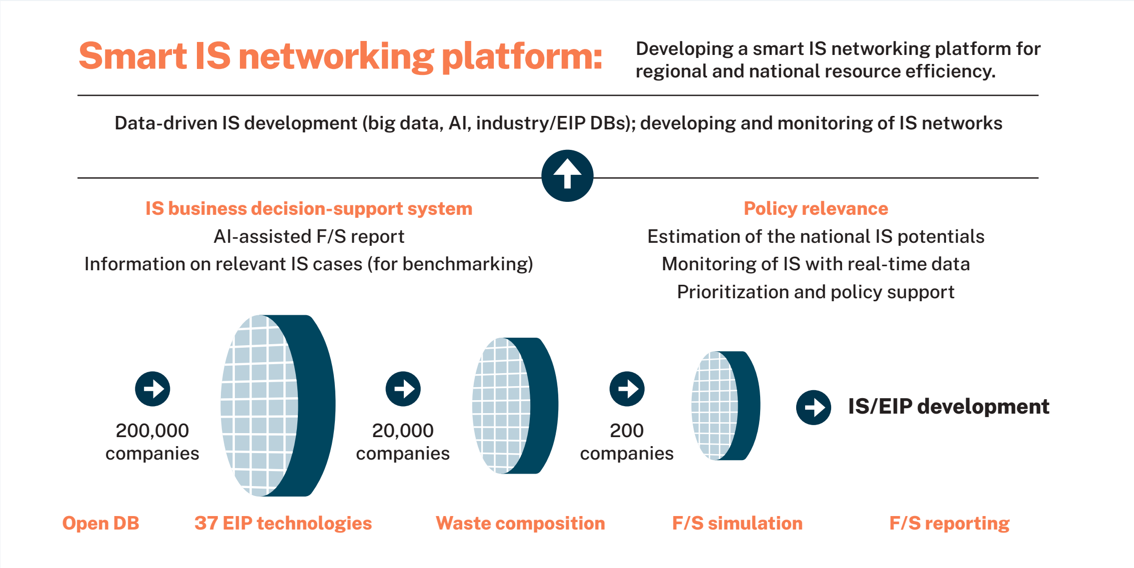
In Korea, a digital platform called the "Smart Closed-loop Grid System" is under development to facilitate industrial symbiosis opportunities. Using Big-Data and artificial intelligence (AI) technologies, this platform will consolidate data available from more than 200,000 companies, identify essential types of industrial symbiosis technologies, and provide information on the successful business models implemented in Korea. The system uses advanced AI-based forecasting technology to estimate properties of materials and by-products, optimize the exchange networks, and generate simulated feasibility studies. The system is designed to identify and match companies that have high potential for industrial symbiosis opportunities based on these feasibility studies (figure B5.2.1).

The system helps achieve optimal resource management by building networks between supply and demand companies—companies that supply waste and by-products and those that demand such materials. It also helps monitor the performance of 235 operational industrial symbiosis networks in real time. It helps create the Korean model of EIPs through:

- Matching supply and demand from the companies with high potential for industrial symbiosis
- Evaluating feasibility
- Developing tailored technologies and identifying technology providers

Developing a comprehensive database from the existing industrial symbiosis activities is crucial to the successful design and implementation of this smart closed-loop grid system (figure B5.2.2). The Big Data standardized and embedded in the system analyzes the performance of EIPs and technical data available from each EIP project, and enables users of the platform to use the data more cohesively.

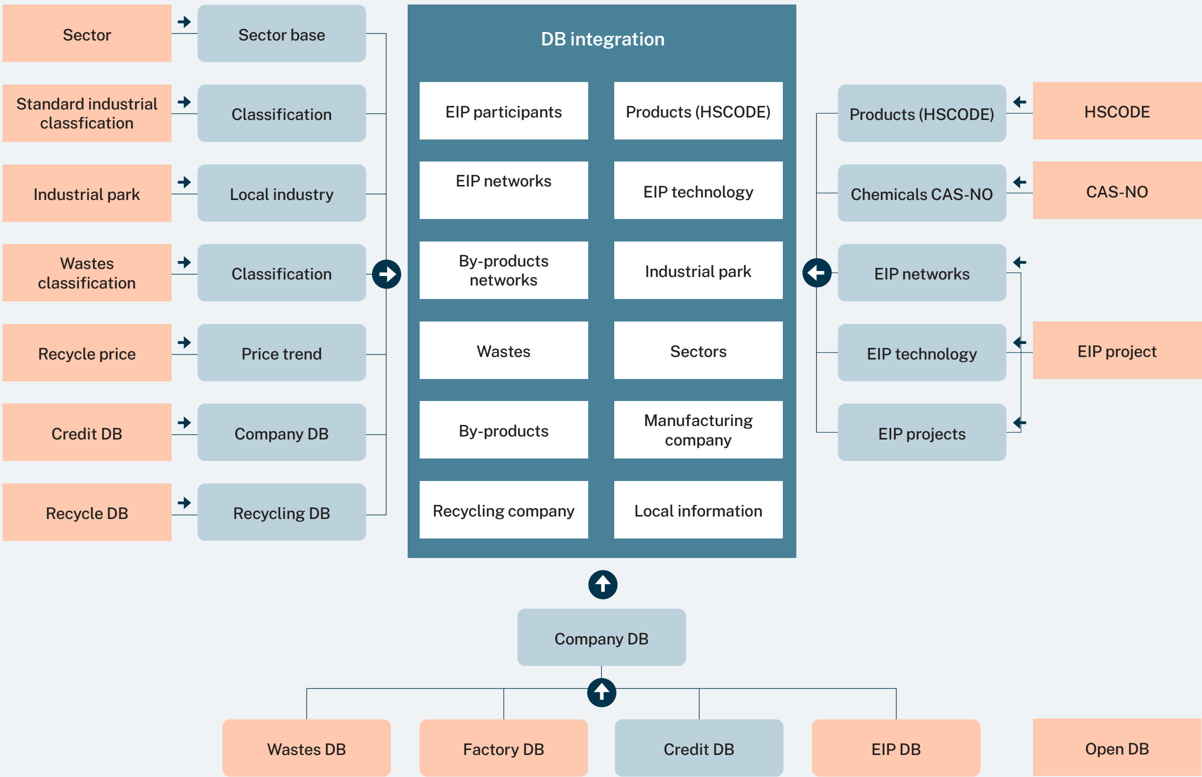
FIGURE B5.2.1 • Data management structure for smart closed-loop grid system



Source: KITECH-KNCPC 2020.

Note: F/S = feasibility studies; IS = industrial symbiosis; DB = database; AI = artificial intelligence; EIP = eco-industrial park.

FIGURE B5.2.2 • Data management structure for smart closed-loop grid system



Source: KITECH-KNCPC 2020; Smart Closed-Loop Grid System: https://www.cppms.kr/scgs.

Note: CAS-No = Chemical Abstracts Services registry number; HSCODE = Harmonized System Codes; DB = database; EIP = eco-industrial park.

BOX 5.3

Biogas and waste incineration technology implemented in Händelö EIP

Overview

Location: Händelö area of Norrköping in Sweden

Stakeholders involved: Lantmännen Agroetanol (bio-ethanol company), E.ON (energy company), Norrköping municipality, Nodra (water and waste management), Norrköping Harbor, Linköping University, Tekniska Verken

Number of employees: Over 500 employees of stakeholder groups including companies operating in the EIP

Background

Händelö, a 600-hectare island in the Baltic Sea, just outside the City of Norrköping in the county of Östergötland in Sweden, has been developed into a center of environmental technology. In Händelö, industries successfully coexist with nature, located as they are on an island with high business and economic potential as well as high natural value (Hatefipour, Baas, and Eklund 2011).

Motivations

- The motivation for the industrial symbiosis occurring at Händelö EIP arose when an ethanol plant decided to locate outside Norrköping. It needed access to sea transport of feedstock grain. Being located in Norrköping, it would also be near many supplying farmers. But maybe the most important feature was the competitive steam provided by the nearby combined heat and power (CHP) plant.
- Once in operation, a large volume of stillage could be used in an existing biogas production facility. This ended when the ethanol plant upgraded and developed its by-product into a protein-rich fodder.

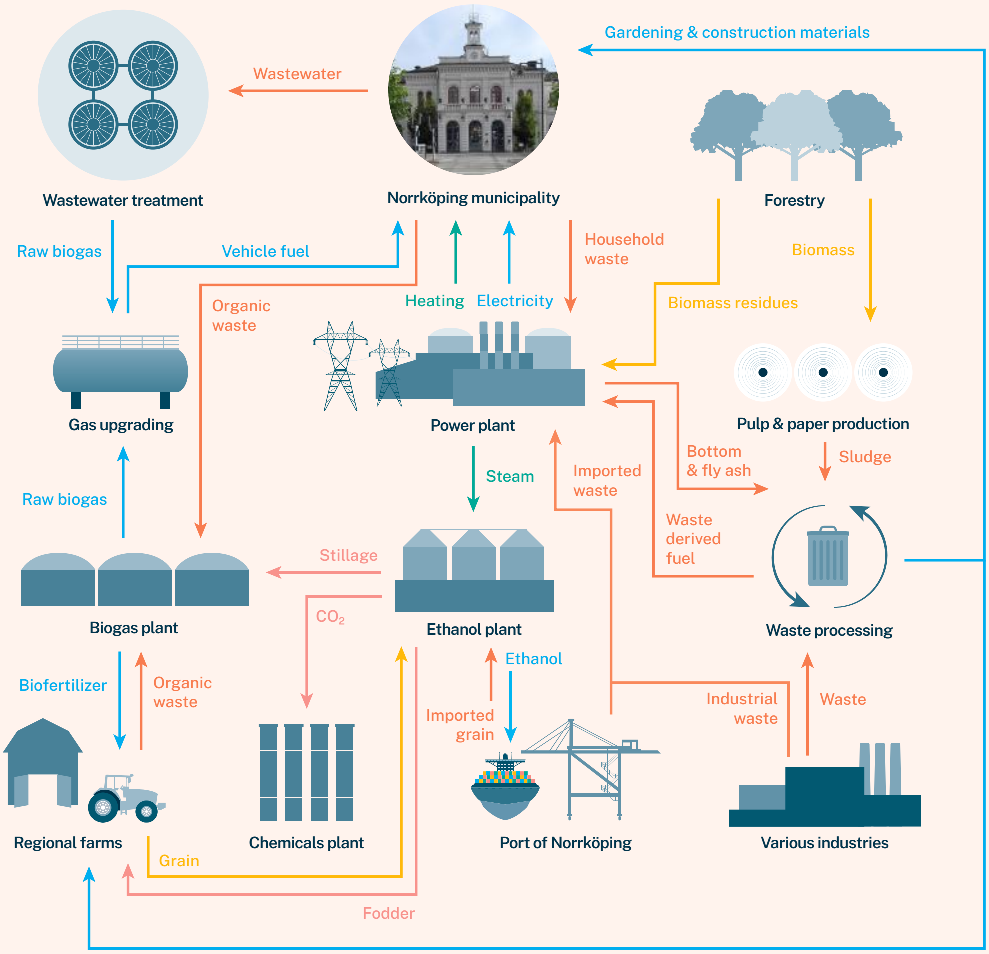
Circular economy solutions and technologies

- A CHP operated by E.ON, located in Händelö EIP, operates on municipal solid waste supplied by the Norrköping municipality and biomass residues from nearby forests, along with small amounts of oil during peak loads (CTCN n.d.; Martin 2010). Wood/return chips, wood waste, rubber tires, and sorted household waste are fed into the CHP.
- The overall heat capacity of the plant is around 1.1 terawatt-hours, including steam, with the power production reaching 300 gigawatt-hours. Of the total energy produced, 57 percent is processed into heat and is delivered to the district-heating network and 14 percent is processed into electricity that is delivered to the grid, which distributes it to the municipality of Norrköping and two other smaller cities. The remaining 29 percent is processed into steam and delivered to a nearby ethanol production plant (Lantmännen Agroetanol). Grain and imported waste are two important raw materials that are shipped by sea to the ethanol plant and the energy company. Both bio-ethanol and carbonic acid is shipped out of the harbor.
- Apart from producing ethanol, its primary product, the by-products of the Lantmännen Agroetanol plant are dispersed as manure to nearby farms, recovered CO_2 to a chemical plant, and stillage to the biogas plant (Svensk Biogas). The biogas plant utilizes the stillage and sewage sludge from the municipal wastewater treatment plant to produce around 2.6 million cubic meters of biogas per year, which is used as biofertilizer, biomanure, and fuel for public and private transportation, after refining. This symbiotic relationship is exemplified in figure B5.3.1.

Challenges

- Sustainable production of biogas can be challenging. Since 2015 the ethanol plant has stopped sending stillage to the biogas plant and instead used it to produce protein-rich fodder. The reason

FIGURE B5.3.1 • Symbiotic relationships between Händelö EIP and Norrköping Municipality



Source: Linköping University.

for this shift was due to the higher commercial value of the product as fodder than as a substrate for biogas. Since 2016, biogas production at Händelö has stopped due to public procurement challenges and because household waste that used to be shipped from the municipality now goes to Linköping instead. The Händelö EIP is investigating whether other commercial parties are interested in reintroducing biogas.

- The water and sewage company in Norrköping, Nodra, is part of ongoing biogas-related projects conducted together with Linköping University. Research has been compiled looking at a future biogas role for Nodra. For a municipal company to undertake a new role, there has to be change in ownership directives so that a public company does not provide unfair competition to a local biogas market. Just recently Nodra has been granted a new role by political majority as a local coordinator of several potential biogas substrate flows. Which commercial actors have an interest in taking the lead is yet to be seen.

Key enablers

- Both the park operators and Norrköping municipality share a strong commitment to undertaking environmentally motivated actions, which has led to the establishment and operation of systems required for material exchange between the municipality and the EIP. The municipality has also developed a market for biogas in transportation, as well as influenced the decision of where to locate Agroetanol's ethanol plant.

- Policies and regulations, such as landfill tax regulations and other requirements of the waste framework directive, are among the key triggers for making substantial amounts of waste available for energy recovery.

- Agroetanol's made a strategic decision to produce ethanol with high environmental performance. As the CO_2 performance of the steam used in the distillation process has a significant impact on the overall CO_2 footprint of the produced ethanol, access to low-CO_2 steam from E.ON was an important factor in the company's decision to locate to Norrköping.

- The innovative capabilities and entrepreneurial mindsets of local enterprises are also acting as a strong driver for the development of new synergies.

- Access to finance is key: Business case proposition ensured the financial support of participating actors, which were supplemented by contributions from the European regional development fund.

Results

Energy consumption/GHG emissions reductions: An annual 120,000 tCO_2

Lessons learned for park operators

It is important to consider the entire system when analyzing the supply of and demand for products and by-products of an ethanol plant. Resource or material flows may alter significantly with market demand and price fluctuations for bio-based material and the upgradability. Investment and operational decisions should be made in the long term. This is obviously very difficult as economic instruments are seldom in place over the long term, which large industrial investment usually requires (Industrial Symbiosis in Sweden n.d.). The presence of strong and efficient facilitators (in this case, municipal authorities and project managers) is required for establishing and maintaining industrial symbiosis projects. Also, curbs on waste disposal supplemented with waste collection infrastructure can help in managing waste dumping and streamlining efforts to handle waste across the park. Recovered materials and by-products, if properly segregated, can help provide an alternate energy source for captive power generation for the park.

Applicability in developing countries: High

Strengths: Industrial parks are often close to urban agglomerations, which facilitates the utilization of municipal solid waste and reduces landfill requirement.

Weakness: The outputs of an incineration plant depend on the composition of waste, and on the development of synergies among park operators and municipal bodies.

Required enablers: Incentivizing municipal bodies to collaborate with industrial park administration.

Sources: Hamilton 2020; Hatefipour, Baas, and Eklund 2011; CTCN n.d.; Martin 2010; Industrial Symbiosis in Sweden n.d.

The park operator can partner with a third party to realize zone-to-firm industrial symbiosis projects, as illustrated in the case of the Vatva Industrial Estate in India. The Vatva Industrial Estate Infrastructure Development Ltd., a special purpose vehicle (SPV) company of the Vatva Industrial Association (VIA), worked with Novel Spent Acid Management, a service provider, to develop and operate centralized infrastructure to recover and reuse spent sulfuric acid within and around the industrial park (box 5.4).

BOX 5.4

Spent acid handling and waste exchange technology in the Vatva Industrial Park

Overview

Location: Vatva (near Ahmedabad) in India

Number of companies: 2,500

Sector distribution: Chemicals, dyes and dye-intermediates, engineering, food and pharmaceuticals, foundries, plastic and rubber, textiles

Number of employees: 120,000

Area: 527 hectares

Year of establishment: 1968

Economic significance: More than $13,500 million revenue

Background and motivation

Vatva is one of the oldest and largest industrial estates operating in Gujarat, India. Vatva's tenant firms are major Indian companies including Godrej, Parle Agro Ltd., Intas Pharmaceuticals, Ltd., Torrent, and Nirma Chemical Works Pvt. Ltd. Well-known government institutes like the National Leather Research Institute, Central Institute of Petrochemicals Engineering & Technology (CIPET), National Standards Laboratory, and Indo German Tool Room are also located within the Vatva Industrial Estate. Spent sulfuric acid is generated from the chemical industrial units operating in Vatva Industrial Estate, with concentration levels ranging between 10 and 30 percent. The individual industries found it difficult to store, handle, treat, or dispose spent sulfuric acid cost-effectively as this acid often contained multiple impurities (Vatva Industries Associations n.d.).

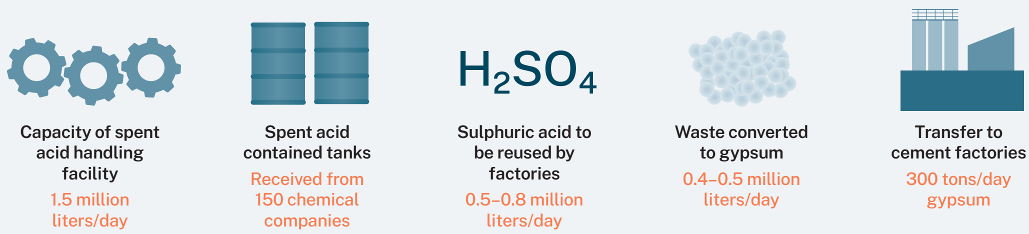
Circular economy solutions and technologies

In Vatva Industrial Estate, Novel Spent Acid Management, a service provider, and a centralized industrial waste exchange and by-product recovery facility were established to collect, segregate, store, and send filtered spent sulfuric acid to the suitable chemical manufacturers in the form of raw material (Novel Waste n.d.). The facility is built on 43,000 square meters of land within the estate. At this facility, spent acid is received in various tanks classified in terms of the level of concentration of sulfuric acid. The facility can handle 1.5 million liters per day and convert 0.4–0.5 million liters of waste per day to be reused for gypsum production. With this capacity, around 300 tons of gypsum are produced per day for sale (figure B5.4.1). The wastewater generated as the filtrate is treated in the effluent treatment plant (ETP) and then sent to the common effluent treatment plant (CETP) for further treatment and joint disposal. Approximately 150 companies around Ahmedabad, Gujarat, have registered for this service.

Economics

- **CAPEX:** $3.1 million (Rs. 23 crore)[6]
- **Financing mechanisms:** In 2003, the Indian government introduced the Industrial Infrastructure Upgrade Scheme (IIUS) to enhance international competitiveness of the domestic industry (Indian Ministry of Commerce and Industry n.d.). It provided quality infrastructure

FIGURE B5.4.1 • Schematic of the spent acid system implemented in the Vatva Industrial Estate



Source: Original compilation.

through the public-private partnership approach in selected industrial clusters/ locations that have greater potential to become globally competitive. The facility in Vatva was developed under this central government scheme.

Business models:

- Spent acid is directly supplied to users to utilize as raw material in their processes to produce value added such as phosphate, ferrous sulfate, and alum.

- Part of the spent acid is neutralized using hydrated lime for the production of gypsum, which is supplied to the cement manufacturing plants as a by-product (Vatva Industries Association 2019).

Results

- Novel Spent Acid Management, the organization handling the spent acid management unit, has been witnessing average annual revenues of approximately $1 million (Novel Waste 2020).

- The amount of recovered and reused waste and resources including spent acid ranges between 0.5 and 0.8 million liters/day.

Lessons learned for park operators

A public-private partnership in spent acid handling technology with a proven business model can lead to sustainable operations, if demand and supply for spent acid products can be established.

The utilization of spent acid reduces any risks related to handling of hazardous acid as well as pollution-related risks, while creating an alternate revenue-generating option for park operators.

Applicability in developing countries: Medium

Strengths: Relatively lower cost of installation. Multiple revenue stream possible.

Weakness: Applicable mainly in industrial parks with industrial processes that require sulfuric acids.

Required enablers: Active involvement of park operators to bring together the source and receiving industries to enable a symbiotic relationship. Public financing for the capital investment of the centralized facility.

Sources: Vatva Industry Association 2019, n.d.; Novel Waste 2020, n.d.

Park operators can also facilitate firm-to-firm industrial symbiosis projects by helping to increase interaction among tenant firms and bringing to the fore symbiotic opportunities, as illustrated in the case of the Kwinana Industrial Park in Australia (box 5.5). In the Kwinana case, industrial symbiosis projects were organically developed with the Kwinana Industries Council acting as the facilitator among tenant firms that led to by-product and product exchanges. Public intervention was minimal in this case. In China, the Tianjin Economic and Technological Development Area (TEDA) played a central role in establishing an industrial symbiosis network among its member companies. Between 2010 and 2013, TEDA organized more than 460 on-site visits, 22 quick-win workshops, and 14 sectoral seminars involving the utility, automobile, electronics, biotechnology, food and beverage, and resource recovery clusters (Shi and Yu 2014). As a result of the initiative, TEDA helped identify 77 industrial symbiosis opportunities and engaged more than 750 small and medium enterprises in the industrial symbiosis projects. The project also generated tangible outcomes: more than 936,000 tons of raw materials were reduced, and revenue was increased by approximately $16 million. Knowledge dissemination among tenant firms focused on the business case of industrial symbiosis solutions, case studies of previous applications and tools, and methodologies to identify industrial symbiosis possibilities and create industrial symbiosis relationship networks.

BOX 5.5

By-product exchange technology in Kwinana Industrial Park, Australia

Overview

Location: Kwinana near Perth in Australia

Sector distribution: Fabrication and construction, high-technology chemical and biotechnology industries, resource processing industries like titanium dioxide pigment production and alumina, nickel, and oil refineries

Number of employees: 30,000

Area: 12,000 hectares

Economic significance: Output of the industrial park is over $11 billion annually[7]

Background and motivations

The Kwinana Industrial Area (KIA) was established in the 1950s and is located in the Western Trade Coast, Western Australia's most significant industrial region. The instance of industrial symbiosis has considerably increased since the late 1980s, providing economic, environmental, and social benefits to the companies involved, neighboring communities, and beyond. The number of symbiotic relationships between firms involving either product/by-product transfer or commercial cooperation reached more than 150 (Kwinana Industrial Council n.d.a). The Kwinana Industries Council aimed at improving the competitiveness of the KIA by creating synergies among tenant companies through increased reuse and recycling of materials.

Circular economy solutions and technologies

Integrated research program was undertaken to identify industrial symbiosis possibilities within the park. The industrial symbiosis projects include both firm-to-firm type and zone-to-firm type. The examples of firm-to-firm industrial symbiosis interventions include: a chemical plant supplying gypsum for residue area amelioration at an alumina refinery; a chemical plant supplying carbon dioxide to an alumina refinery residue area; and utilization of by-products generated by a steel manufacturer at the HiSmelt Pig Iron Plant. Examples of zone-to-firm industrial symbiosis interventions include a high-pressure steam network established between combined heat and power (CHP) plants and the oil refinery. A CHP with a total installed capacity of 116 megawatt-hours generates high-pressure steam and supplies it to the oil refinery.

Results

- A chemical plant produced 1.3 million tons of by-product gypsum during the 1980s, which was stored at the plant site. Of this, 10,000 tons of gypsum was reused by the alumina refinery company every year for plant growth and soil stability. Building on this interaction, the chemical plant also supplied CO_2 to the alumina refinery, which helped save 70,000 tons of carbon dioxide (tCO_2) greenhouse gas emissions annually (Harris 2007).

- The exchange of high-pressure steam helped save 170,000 tCO_2 per annum. This partnership also helped the oil refinery plant save $10.3 million[8] in terms of CAPEX, while at the same time providing a reliable, cost-competitive source of steam and electricity (Harris 2007).

- In addition, awareness of the industrial symbiosis potential within the industrial cluster improved. By-products once stored or sent to the landfill are now being seen by tenant and neighboring companies as an inputs into other industrial production processes. Energy in the form of steam or hot water is also seen as an economically viable resource that can be exchanged.

Lessons learned for park operators

Both zone-to-firm and firm-to-firm industrial symbioses can be scaled up even without substantial public sector interventions. Park operators can play a central role in facilitating the conversation among interested tenant firms and mobilize technical assistance to estimate potential industrial symbiosis networks between firms in an industrial park. Development of industrial symbiosis infrastructure accordingly provides greater opportunity of exploiting the industrial symbiosis potential. Pre-planning can also help secure financing in the early stages. In addition, technologies proven effective in extracting by-products or materials from the source production processes and make them useable and valuable in other production processes should be available to realize the industrial symbiosis in a cost-effective manner.

Applicability in developing countries: High

Strengths: A low-cost, high impact solution to resource efficiency.

Weakness: Maintaining multiple industrial symbiosis exchanges require dedicated personnel allocation by park operators.

Required enablers: Communication of convincing business cases and presence of proven technology lead to tenant firms' improved understanding of the benefits associated with industrial symbiosis projects.

Sources: Harris 2007; Kwinana Industries Council n.d.a, n.d.b.

Park operators can seek to improve technical and economic feasibilities of industrial symbiosis projects and increase awareness of the business cases among tenant firms through testing facilities or demonstration projects. These strategies may require collaboration with research institutions to stimulate research and development, enhancing access to financing or undertaking knowledge dissemination as illustrated in the Kitakyushu Eco-Town projects implemented in Japan (box 5.6).

BOX 5.6

Demonstrating technical feasibilities of industrial symbiosis in eco-towns, Japan

In Japan, EIPs are implemented in the form of eco-towns, wherein prefecture and city governments or municipalities are involved in developing the eco-town plans.[9] Established under the Eco-Town Program in 1997 with a zero-emission concept, the plans were jointly approved by the Ministry of Economy, Trade and Industry, and the Ministry of the Environment. Infrastructure and recycling facilities were provided to scale up industrial symbiosis networks within and across participating industrial parks and cities through financial support from central government. Kitakyushu Eco-Town is one of the 26 eco-town programs approved by the Government of Japan, wherein the city government has helped support activities to demonstrate the technical feasibility of industrial symbiosis projects in the eco-town context.

The City of Kitakyushu provided research and development support and developed a cluster of EIP technology testing facilities by extensively engaging with local universities and companies, as well as research institutions operating in the nearby Kitakyushu Science and Research Park (Kita-ecotown 2019). This research partnership and the facilitation of EIP testing/demonstration facilities helped scale up the adoption of the most effective recycling technologies and attract private investment in the construction of state-of-the art recycling facilities. The city government also provided financial support for companies investing in the research and development of EIP technologies through Environmental Industry Financing Fund and the Environmental Future Technologies Development Fund. The funds focused on supporting the development of technologies related to waste processing, recycling, environmental conservation, green product development, new energy sources, and energy savings. As of 2019, 60 research projects had been conducted as a result. Other funds from the Government of Japan such as the Green Product Development Fund and the Energy-saving Facility and Development Fund also provided additional support in the form of preferential loans and guarantees.

Lessons learned for park operators:

Creating partnerships with research organizations to identify possible implementation areas for EIP technologies and industrial symbiosis possibilities, coupled with financial support from government bodies, can help stimulate resource efficiency in industrial parks. Investment in identifying, liaising, and setting terms of engagement with appropriate research and funding agencies is required by park operators to stimulate the uptake of EIP technologies.

Park operators can also help aggregate the financial requirements of firms participating in industrial symbiosis solutions, thereby creating opportunities for better financing conditions. Collaborating on financing options with government agencies and similarly, with other bilateral and multilateral financing institutions, can also improve the financing landscape for industrial symbiosis solutions.

Source: Environment Bureau, City of Kitakyushu 2019.

Operational challenges

- **Disruption in material flows from waste sources:** In case of unforeseen circumstances, production stops at the source firm, or waste volume reductions due to the adoption of a new technology, the end user may experience a disruption in supply. End users may hedge this risk by maintaining a source on standby. This may not always be feasible, and the backup may not be able to adequately meet demand in case of an emergency.

  The risk arising from dependency on the operational decisions of another firm is a key challenge in implementing industrial symbiosis projects.

Key enablers

- **Enabling regulatory framework:** Regulations and policies that give direction to actions at the local/national/regional level can have a significant impact on the adoption of industrial symbiosis. The European Union adopted the First Circular Economy Action Plan in 2019, which contains 54 actions cutting across all sectors and the material production, consumption, and disposal life cycle (European Commission n.d.a).

- **Incentives and innovative financing mechanisms:** Governments can directly finance infrastructure and facilities to help stimulate private sector investment in industrial symbiosis solutions through public-private partnerships as in the Vatva Industrial Estate in India. Governments can also help park operators and tenant firms access multi-lateral funding for developing industrial symbiosis projects, as in the Händelö EIP case. As in the Korean and Japanese cases, they may also do so through R&D investments, preferential loans and guarantees, or financing prefeasibility or feasibility studies by leveraging a dedicated fund.

- **Shift in the business model of park operators:** As exemplified by the Händelö and Kwinana EIPs (box 5.3 and box 5.5), the active involvement and support of park operators can scale up industrial symbiosis projects and the adoption of relevant technologies. To accelerate industrial symbiosis, park operators need to rethink their business models to include their new role as service providers. This may require the expansion of their business model from the traditional one of facility management (i.e., operation and maintenance of park infrastructure) to being an integrated service provider of consultancy, negotiation, and implementation support for tenant firms seeking to identify industrial symbiosis solutions.

- **Guiding tools and methodologies:** Innovative digital platforms, tools, and methodologies can facilitate the identification of industrial symbiosis opportunities. As illustrated in box 5.1 and box 5.2, these tools can help preassess waste inventory and industrial symbiosis potential, prioritize sectors that can create synergies, or simulate feasibilities. Platforms such as FISSAC[10] and SHAREBOX,[11] can be helpful in creating industrial symbiosis knowledge bases that are sector specific.

- **R&D and testing facilities:** As illustrated in box 5.6, improved access to research centers and collaboration with research institutions can also help improve the knowledge base for industrial symbiosis technologies and stimulate R&D in exploring industrial symbiosis potentials, technologies, and their feasibility. Small-scale testing facilities and demonstration sites established on the industrial park site can not only help enhance R&D prospects but also attract private investment in state-of-the art facilities.

5.4 • Key takeaways for park operators and policy recommendations

Scaling up material and waste heat recovery through industrial symbiosis technologies can create additional business values and revenue streams for both park operators and tenant firms. Park operators can take forward the following takeaways to accelerate this process:

1. **Raise awareness among tenant firms of the business case for industrial symbiosis solutions and available technologies**, as well as how these solutions can help create additional values and strengthen the competitiveness of each firm in its respective market.

2. **Collect, monitor, establish, and assess comprehensive databases** on the types and characteristics of materials, by-products, and other resources generated within the industrial parks.

3. **Stimulate discussion among tenant firms to identify and realize industrial symbiosis opportunities** available among them. Park operators can leverage digital platforms or tools to provide firms with access to information on successful business models of industrial symbiosis solutions, and tools and methodologies for assessing related potential.

4. **Encourage partnerships with external research organizations** to help facilitate the assessment or development of technically viable industrial symbiosis solutions among tenant firms.

5. **Pool financing requirements** for possible industrial symbiosis and material/waste heat recovery solutions. Related steps may include:

    - Negotiating better-than-market-lending terms with banks and financing institutions on zone-to-firm industrial symbiosis solutions with a proven business model.

    - Working with national and local governments and international financial institutions to gain better access to financial support for the implementation of solutions that have strong technical and economic feasibilities.

It is not sufficient for park operators to act alone to scale up the adoption of industrial symbiosis solutions and technologies to recover material and waste heat. Regulatory and policy-level support both at the national and local levels will be required. Table 5.7 provides the list of policy levers that can stimulate the uptake of these technologies, including regulations, financial incentives, market development, national and international partnerships, and technical capacity building activities.

TABLE 5.7 • Policy recommendations to catalyze the adoption of industrial symbiosis solutions and relevant technologies

Area of action	Key barriers	Recommended policy action
Waste reduction and management	» The societal cost of waste generation is not internalized, and therefore firms have limited incentives for implementing additional efforts to go beyond compliance levels. » Value creation from material recovery is yet to be realized by businesses.	» Regulations increasing the cost implication for waste producers » European Union: National legislation based on three main principles among others have fostered the uptake of industrial solutions in industrial parks: • Polluter pays: The costs of waste management shall be borne by the original waste producer or by the current or previous waste holders. • Extended producer responsibility (EPR) shifts responsibility for waste management from consumers and authorities, who were the traditional assignees, to the producers of the products. • Integrated product standards that encourage eco-design[a] are a toolbox of policy instruments, applicable across the life cycle of products to reduce waste generation. Voluntary or mandatory measures including economic instruments, substance bans, voluntary agreements, environmental labelling, and product design guidelines and standards.
Technical and commercial capacity development	» Limited awareness of possible industrial symbiosis technologies available in the national/regional markets. » Limited know-how on industrial symbiosis project development and network operations, including technology providers and personnel for designing and operating the network. » Limited knowledge on technical and financial feasibilities of industrial symbiosis solutions.	» **Developing guidelines** to help industrial park operators understand key requirements of industrial symbiosis opportunities: • Italy's law on "Ecologically Equipped Industrial Areas" provides guidelines for industrial park developers to maximize investments in shared infrastructure and support tenant firms in establishing material and energy exchange networks. » **Technology platforms** and dedicated bodies can be devised to act as a one-stop information source for park operators related to industrial symbiosis: • In the Republic of Korea and the European Union, the Smart Closed-loop Grid System and FISSAC are digital platforms developed to facilitate information exchange to support industrial symbiosis network development and replicate pilot schemes at local and regional levels.
Improved access to financing	» High capital investment cost. » Financial benefit realization.	» **Financial support for feasibility studies:** • The government of Korea provides financial support to industrial parks to identify potential economic benefits and undertake feasibility studies. Over a 15-year tenure, 247 industrial symbiosis projects have been successfully implemented, drawing private investments and scaling up business models » **Providing tax benefits for organizations participating in industrial symbiosis interventions:** • In Finland, a tax relief program has supported the establishment of industrial symbiosis networks for waste exchange and uptake.
International cooperation	» Limited availability of technical expertise in the local/regional market. » Cost implications of importing technology from international players.	» Leverage support from international financial institutions with deep experience in support identification, design, and implementation of industrial symbiosis projects. » Undertake bilateral engagement exercises to facilitate technology transfer and establish R&D facilities to develop industrial symbiosis solutions suited to local conditions and requirements.

a For further information, see European Commission (n.d.b).

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Endnotes

1. ORC systems with outputs of 1–1.25 megawatts are considered large-scale units.
2. Recovery and utilization of waste heat depend on the temperature of the heat generation source. The waste heat is divided in three categories: low grade (<100°C), medium grade (100°C–400°C), or high grade (>400°C). Low-grade waste heat can only be recovered effectively when there is a large quantity of waste heat and a ready use for it, while recovery and utilization of high-grade heat is relatively easy due to its high energy content.
3. For common infrastructure components such as boilers, captive power plants, centralized HVAC systems, cooling towers, and cogeneration units, a structured analysis of steam, water, and cooling systems can reveal how steam or cooling generation from hot or cold fluids can be optimized while meeting tenant firms' demands.
4. For example, a detailed assessment of the biogas generated from the secondary treatment processes involved in CETP and STP operation requires field measures to collect the flowrate and composition.
5. For further information and guidance on how to conduct the material flow analysis, see UNIDO, World Bank Group, GIZ, and Ministry of Trade, Industry and Energy (2019).
6. Converted to US dollars ($) at the 2020 annual average exchange rate of $1 = Indian rupees (Rs) 74.1, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.
7. Converted to US dollars ($) at the 2020 annual average exchange rate of $1 = Australian $1.45, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.
8. Converted to US dollars ($) at the 2020 annual average exchange rate of $1 = Australian $ 1.45, based on the yearly average currency exchange rate provided at: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.
9. The Japanese Ministry of Economy, Trade and Industry (METI) and the Ministry of Environment (MOE) approved 26 eco-town programs. Under a nationwide program to scale up eco-towns, more than 62 recycling facilities and 90 circular cities were developed between 1997 and 2011, with financial support from the central government.
10. Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry across the Extended Construction Value Chain (FISSAC): https://fissacproject.eu/en/fissac-software-platform/.
11. SHAREBOX, Secure Sharing: http://sharebox-project.eu.

6 Future Prospects

Circular economy principles are at the forefront of the competitiveness agenda for industrial sectors, including for industrial parks, their tenant firms, other industries connected to these parks and firms, and even the cities in which industrial parks operate. This report intends to provide practical recommendations on how industrial parks can promote the circularity of resources and strengthen competitiveness through innovative technologies and business models, and what governments can do to support such initiatives. It also aims to assist policy makers in identifying enablers of and barriers to the adoption of the proposed technologies. Several lessons have emerged from this global study, as outlined below.

6.1 • Key lessons and recommendations

The key message of the report is that circular economy interventions are not just environmentally beneficial but also economically viable, and hence, can improve the competitiveness of industrial parks and tenant firms. In the Bursa Organized Industrial Zone in Turkey, for example, the park operator renovated its conventional water supply system by adding membranes, and managed to provide process water to its tenant firms at a competitive price that is nearly five times less than the price offered by the local municipal government (chapter 4, box 4.2). In Industriepark Höchst, Germany (chapter 3, box 3.9), the park operator introduced a co-digestion plant that produces biogas from industrial biosolids. This generates a revenue stream from producing electricity and steam along with biomethane sold and injected into the national gas grid. In the Händelö Eco-industrial Park (Norrköping, Sweden), biogas and waste incineration technologies are reducing greenhouse gas emissions by 120,000 tCO_2. In the Point Lisas Industrial Estate (Trinidad and Tobago), installing a desalination plant to address dwindling groundwater resources has helped tenant firms avoid the installation of a costly ion-exchange plant and significantly lowered their water tariffs. The revenue generated from this approach has helped the industrial estate supply water to a nearby urban agglomeration free of charge, thereby also helping to improve the local economy.

Eco-industrial parks (EIPs) are important building blocks of the circular economy. Over the past two decades, the number of EIPs in countries outside the Organisation for Economic Co-operation and Development (OECD) grew by 5.8 percent annually — faster than in OECD countries (4 percent). Yet there is still a significant gap between developed and emerging economies in terms of the adoption of innovative infrastructure and service systems, technologies, and business models that promote EIPs and enhance the reuse of waste and resource circularity. Industrial park developers and operators can assess the "circularity gap" using the International Framework for Eco-Industrial Parks and take actions to close it (for a selected list of performance indicators, see chapter 1, box 1.2).

Industrial park developers and operators have vital roles to play in mainstreaming circular economy principles in industrial park operations by improving the circularity of energy, water, materials, and by-products during production processes. Industrial park operators can, for instance:

» Foster smart resource consumption by leveraging innovative business models. As exemplified in the cases of the Industriepark Höchst (chapter 3, box 3.9) and Konya Organized Industrial Zone (chapter 3, box 3.5), an existing power source can be supplemented by either additional renewable power capacity or third-party supply. For effective energy management across park-wide operations, park operators can work with an energy service company to provide on-demand energy services to tenant firms, as observed in the Carnia Industrial Park (chapter 3, box 3.2).

» Prioritize regenerative resources and renewables for common infrastructure investments.

» Leverage innovative material recovery technologies and use waste as a resource. Solid municipal waste, biomass, and wastewater sludge can be used to generate biogas or power. Salts extracted from wastewater sludge can provide alternate revenue generating options, as can the extraction of metals from wastewater streams generated by electroplating firms.

Tailor technical designs to local contexts while maximizing existing infrastructure

Circular economy strategies introduced in this report are not one size fits all; their technical viability varies according to the availability of technologies, as well as a range of other enablers and limitations identified on the ground. For example, to produce biogas cost-effectively, park operators need to make sure that they have access to a steady and consistent flow of biomass, organic waste, or sludge and check if a distribution network is locally available (chapter 3, subsection 3.3.3). Leveraging such locally available resources and enablers effectively, the park operator can bring down capital and operational costs, and improve its business model. The technical design and installation of floating solar photovoltaic systems in coastal economic zones also need to take into consideration the potential local impacts of extreme weather events such as storm surges, cyclones, heavy rains, and high winds on equipment and system operations. And, as illustrated in the case of Bursa (chapter 4, box 4.4), a water supply system that reuses treated wastewater will not be technically and economically practical if the chemical composition of mixed wastewater is too complex.

Create joint values through collaboration

Promoting stakeholder collaboration is key to developing innovative, locally tailored, and technically and economically workable circular economy solutions. Key stakeholders in the process of mainstreaming circular economy solutions at the park level include park developers and operators, tenant firms, industrial associations, local suppliers, infrastructure operators, national and local governments, service or technology providers, and financial sector stakeholders. Park operators can catalyze a stakeholder platform to catalyze collaboration. Above all, engaging tenant firms is essential to maximize the otherwise underutilized resources, land, infrastructure, services, waste, and by-products available within and around industrial parks. For example, a plan to increase captive renewable energy generation through rooftop photovoltaic systems is not viable without tenant firms' willingness to maximize the use of their rooftop space (and thus address constraints in useable industrial land). In the Händelö case (chapter 5, box 5.3), it was crucial to involve the municipal government in making biogas production from municipal solid waste technically and financially feasible.

Revisit existing business models and pilot innovations

Industrial park operators need to navigate and build new business models to mainstream circular economy approaches; these include innovative contract agreements and financing options such as public-private partnerships. To develop good business cases, park operators and relevant stakeholders can collectively review, for instance:

- Their technical and financial capacity to undertake measures to improve resource circularity
- Potential financial benefits to be derived by implementing measures for improving resource circularity
- Tenant firms' willingness to reconfigure their assets (including buildings, facilities, machinery involved in production processes and other equipment required for operations)
- The technical feasibility of reconfiguring existing assets to improve resource circularity in tenant firms' operations as well as in common infrastructure
- Availability of external financing options, especially the option of leveraging private sector partnerships for project financing
- The privacy of proprietary information (such as profit margins and customer information) shared through digital platforms
- Existing environmental, social, and economic performance monitoring frameworks for park operations, as well as data collection and database management systems, to examine the scope for improvement and identify ways to integrate digital technologies in performance monitoring.

Creating a good business case includes envisioning park operators' new roles as service providers, and rethinking parks' circular economy strategies from the perspective of broader and integrated energy, water/wastewater, and waste management plans. If it makes economic sense, park operators shift into the role of service providers from their traditional role as industrial real estate and infrastructure developers. As illustrated by the cases of the Carnia and Höchst industrial parks, park operators can collaborate with energy service companies to offer tenant firms energy trading and management services. For example, they may negotiate directly with utilities to provide electricity to tenants at a price lower than the market price (chapter 3, box 3.3). Meanwhile, capital investments in captive renewables, biogas plants, wastewater treatment and reuse systems, or waste recovery plants can be informed by integrated energy, water, and waste management plans to ensure win-win solutions for all relevant stakeholders.

Park operators need to constantly monitor, evaluate, and improve the performance of system designs and business models after implementation. This is to ensure that objectives are met or exceeded, and to identify areas for improvement. Use of an automated energy management system can help park operators monitor and control energy consumption to ensure objectives are met.

Strengthen institutional capacity and skills competence

The status of existing infrastructure systems, institutional capacity, and the availability of skilled operators are critical concerns. In the Tianjin Economic-Technological Development Area (Tianjin, China), sustained efforts in organizing onsite visits, quick-win workshops, and sectoral seminars on resource recovery have helped the park operator identify 77 opportunities for industrial symbiosis across 750 small and medium enterprises (chapter 5). As a result of the measures implemented from the set of identified opportunities, 930,000 tons of raw material consumption were reduced while revenues were increased by $16 million. The technical capacities of national and local governments, industrial park operators and their employees, technology and service providers, firms, and financial sectors evaluating investments need to be strengthened in concert with the introduction of innovative technologies. Park operators in developing countries may not always have in-house capabilities and the ability to design, maintain, and operate infrastructure that features novel technological designs. In these contexts, technical assistance, including skills training of park operators, technology providers, and relevant government agencies would be required.

Leverage digital technologies and platforms

Digital access and engagement can boost markets not only for new products, but also services, underused assets, secondary materials, and human capital. It is important to establish information communication and technology infrastructure that enables data collection, information management and sharing, and real-time communication between relevant stakeholders. For example, in the Republic of Korea, a digital platform using Big Data and artificial intelligence technologies to collect and analyze data on EIPs' technical performance is under development to aid identification of potential industrial symbiosis opportunities (chapter 5). The tool assimilates large data sets available from participating companies to identify 37 subcategories of industrial symbiosis technologies and provide information on types of materials, by-products, sectoral profiles, technology providers, and potential by-product exchange networks. It also conducts feasibility studies based on successful EIP business models.

Policy and financial supports are crucial

Park operators cannot implement all these actions alone. Policy and financial incentives are critical to addressing barriers and creating synergies among various circular economy solutions adopted within and across industrial parks. This report shows a significant gap in the penetration of sustainable, low-carbon technologies in industrial parks between developed and developing economies. Developing countries need to still catch up in terms of the regulatory reforms, access to finance, and infrastructure investments that scale up the adoption of innovative technologies to facilitate EIP development. Policy makers in these countries should revisit and modify existing regulatory frameworks, or even consider enacting new ones, to catalyze public and private investment in innovative EIP technologies. This can help create a new market for relevant technologies and eventually bring down the costs of deploying technologies at the park level. For example, in India, a policy push at the national and state level (involving both regulatory requirements and incentives) in support of zero liquid discharge and rainwater harvesting technologies increased the installation of these systems in industrial parks.

Policy actions can also impose fees, reduce resource consumption, and introduce incentives to stimulate the reuse of materials, by-products, and wastewater that would otherwise be disposed and underutilized. For example, the Malaysian government increased water tariffs for different levels of industrial consumers in the face of increasing water demand for industrial production. Such actions can prompt greater recognition of the need to adopt technologies to use/reuse rainwater and treated wastewater. Incentives can also help promote the uptake of similar technologies. For example, facing water constraints, the Mexican government provided financial incentives for the installation of wastewater treatment plants that reuse wastewater to a significant degree (by 30 to 60 percent). While the causal link between various types of policy actions and the adoption of innovative technologies in industrial parks cannot yet be confirmed, EIPs in Malaysia and Mexico show high rates of wastewater/water reuse according to this report's initial assessment. In Malaysia, four out of six self-declared EIPs have adopted rainwater harvesting, and in Mexico, eight out of nine EIPs recycle water leveraging their common effluent treatment plants.

6.2 • Moving forward

The solutions and technologies used to apply circular economy principles at the level of the industrial park — and at larger economic scales — will continue to evolve. The evidential basis that justifies park-level investments and policy reforms is not definitive, especially when these investments entail innovative technologies, and vary according to the local contexts and available resources and waste to be reused. Therefore, continuous research, monitoring, and evaluation of baselines and various business models are needed to understand what worked or did not work, and why.

More case studies and pilots will be needed to evaluate the full life-cycle costs and benefits of circular economy planning and actions for industrial parks, tenant firms, and the local economy. These case studies and pilot projects need to collect useful data and deepen understanding of how the circular economy approach can contribute to greenhouse gas emissions reductions, resource optimization, waste minimization, service reliability improvements, investment returns, and the creation of better jobs for vulnerable economic groups including women. They can also gauge particular projects' suitability for various industry stakeholders, and their marketing potential. Industrial park developers and operators, investors, financial sector stakeholders, and governments would need this range of information to increase the uptake of circular economy interventions and recommendations. More research is also needed on how existing and new financial instruments can incentivize the smart use of resources, waste, and by-products generated in industrial parks and nearby areas. Institutional means to better integrate circular economy principles in park development and operation would merit further investigation.

Synergies between circular economy practices in industrial parks and industry sectors should also be investigated to maximize potential benefits. Understanding the spillover effects and creating synergies between circular economy innovations applied across different industry sectors and industrial parks is essential. Countries and leading industry stakeholders have already embarked on deploying innovative technologies for decarbonization to scale up circular economy practices. These include but are not limited to: demand-side measures, energy-efficiency improvements, the electrification of heat with renewables, batteries, smart grids, digital solutions, factory energy management systems, the use of hydrogen as a feedstock or fuel, the use of biomass or waste materials as a feedstock or fuel (e.g. use of slags, used tires, and synthetic resin from waste instead of fuel for cement manufacturing), and carbon capture and storage or usage. They are also implementing other digital innovations that utilize the Internet of Things, Big Data, and artificial intelligence to monitor and optimize energy use. These technologies can be adopted in industrial park operations and monitoring while maximizing potential synergies with circular economy innovations happening in various sectors.

Development partners can support client countries and park operators to develop innovative business models and mainstream circular economy principles. They can share international benchmarks; provide technical assistance in prefeasibility and feasibility assessments; support institutional capacity building and skills training; and help pilot emerging circular economy solutions, technologies, and business models to mainstream circular economy principles in industrial park development and operations. Development partners can also help enhance access to finance for governments to catalyze or scale up circular economy solutions in industrial parks and beyond.

The World Bank Group is already working with countries to track and build business cases and advance our understanding in these areas. By targeting the various stages of the industrial park development process, the World Bank aims to address challenges and concerns, build countries' knowledge and capacity, and help scale up circular economy approaches in industrial parks around the world. In Bangladesh, China, Morocco, Pakistan, Turkey, and Uzbekistan, the World Bank Group is already incorporating the lessons learned from this global study into its programs to support industrial park operators, economic zone authorities, other coordinating agencies, and investors.

The World Bank Group welcomes the opportunity to discuss options and provide support in scaling up EIP technologies with interested stakeholders. Organizations interested or involved in the development and implementation of EIPs are invited to inquire about this support by writing to Etienne Raffi Kechichian, ekechichian@worldbank.org.