A review of the National Eco-Industrial Park Development Program in Korea: progress and achievements in the first phase, 2005–2010

Jun Mo Park a, Joo Young Park b, c, Hung-Suck Park a, d, * 

a Department of Civil and Environmental Engineering, University of Ulsan, Ulsan, 680749, South Korea 
b Center for Industrial Ecology, School of Forestry and Environmental Studies, Yale University, 195 Prospect Street, New Haven, CT, 06511, United States

c School of Management, Universidad de los Andes, Bogotá, Colombia

d Ulsan EIP Center, Korea Industrial Complex Corporation, Ulsan, 680817, South Korea

Abstract

This paper provides a comprehensive review of the first phase of the Korean National Eco-Industrial Park (EIP) Development Program from 2005 to 2010. The main objectives of this review are to introduce how Korea established its own approach to nationwide eco-industrial development and to examine the program’s successes and limiting factors to draw lessons about how industrial symbiosis can be developed successfully elsewhere. The Korean EIP program emerged from a context of 50 years of industrial development to transform traditional industrial structures into EIPs using cleaner production at the industrial park level. During the first five years, regional EIP centers established at five pilot sites developed and implemented 47 resource-sharing projects, which generated considerable economic and environmental benefits. This was possible due to an institutional system that effectively combined top-down and bottom-up approaches and to the mediating role of regional EIP centers, which bring together local stakeholders from businesses, governments, and research organizations. By learning during the first phase, Korea has established its own model for eco-industrial development that will continue to develop during the second and third phases.

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* Corresponding author. Department of Civil and Environmental Engineering, University of Ulsan, Ulsan, 680749, South Korea.

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1. Introduction

The concept of eco-industrial parks (EIPs) originated in a seminal article by Frosh and Gallopoulos (1989). They envisioned industrial ecosystems that optimize resource flows by reusing waste materials from one process as a feedstock for another process. After an actual model industrial ecosystem was uncovered in the small Danish industrial town of Kalundborg (Ehrenfeld and Chertow, 2002; Ehrenfeld and Gertler, 1997), collective and shared resource use among co-located industries was termed industrial symbiosis (Chertow, 2000, 2007). Since then, industrial symbiosis has been adopted in many private initiatives and public policies around the globe as a way to reduce the environmental impacts of agglomerated industrial production (for reviews of scholarly work and practices in industrial symbiosis, see Massard et al. (2012), Yu et al. (2014) and Chertow and Park (2015)).

Despite increasing efforts to develop and implement industrial symbiosis around the world, many attempts have not led to tangible outcomes (Gibbs and Deutz, 2005; Heeres et al., 2004). Various barriers to industrial symbiosis have been observed, analyzed, and categorized into technical barriers (e.g., composition of industries, characteristics of materials, availability of recycling technologies), economic barriers (e.g., upfront investment and costs for processing, transportation, and transactions), legal/regulatory barriers (e.g., regulations that limit waste reuse, administrative burdens related to regulatory compliance), and social barriers (e.g., lack of awareness and motivation, resistance to sharing proprietary information, lack of communication and social relationships, stakeholder and institutional capacity) (BCSD-GM, 1997; Fichtner et al., 2005; Gibbs, 2003; Mirata, 2004; Tudor et al., 2007). Lessons from previous experiences particularly point to the importance of social factors (Boons and Spekkink, 2012; Chertow and Ashton, 2009; Hewes and Lyons, 2008; Howard-Grenville and Paquin, 2008; Jacobsen, 2007) and challenges of developing industrial symbiosis based on optimized material flows without nurturing a systemic managerial approach.

Above discussion relates to the debate about whether industrial symbiosis can be deliberately planned. Some earlier research focused on replicating Kalundborg, particularly through top-down planning (Roberts, 2004; van Leeuwen et al., 2003), but some efforts were focused on replicating Kalundborg, particularly through top-down planning (Roberts, 2004; van Leeuwen et al., 2003), but others were more successful in encouraging industrial symbiosis (Fichtner et al., 2005; Gibbs, 2003; Mirata, 2004; Tudor et al., 2007). Lessons from previous experiences particularly point to the importance of social factors (Boons and Spekkink, 2012; Chertow and Ashton, 2009; Hewes and Lyons, 2008; Howard-Grenville and Paquin, 2008; Jacobsen, 2007) and challenges of developing industrial symbiosis based on optimized material flows without nurturing a systemic managerial approach.

2. The emergence of the Korean national EIP program

Industrial complexes have fueled the rapid economic development of Korea since the establishment of the first five-year economic development plan in 1962 (NAK, 2011). In the 1960s, light industries such as textiles and footwear were promoted to increase exports using inexpensive labor in urban areas. However, increasing global competition for light industries in the early 1970s led to a significant transition in industrial development policy. The “Industrial Base Development Promotion Act” of 1973 established large specialized industrial complexes in areas such as Ulsan and Pohang. The 1980s were a period of balanced growth during which small industrial clusters were developed in towns and rural regions, particularly in the central and southwestern parts of Korea. The policy in the 1990s specifically focused on developing technology for knowledge-based economic development; however, in 2000, those policies were diversified to promote high-tech industries, green industries, and innovative industries to enhance the competitiveness of existing industrial complexes. As of 2013, Korea contained 1033 diverse industrial complexes covering 1387 square kilometers of land. More than 72,000 business units in those complexes employ 2,010,000 workers and produce goods worth 1032 billion dollars (KICOS, 2013). That represents 72% of the national economic output, which has a nominal gross domestic product of 1032 billion dollars (IMF, 2013), as well as 8% of employment (KICOS, 2013) and 77% of exports (KCS, 2013).

Although industrial complexes have been the engine of Korea’s economic growth, the country’s industrial base has aged and caused significant environmental problems. Industrial activities concentrated in industrial complexes consume an enormous amount of resources and generate massive amounts of waste production, waste treatment, and disposal. In South Korea, industrial symbiosis is manifested in the national EIP program initiated in 2005 (Behera et al., 2012; Park et al., 2008), which provides a unique approach to industrial symbiosis development. Korea has about 1000 industrial complexes, which have fueled rapid economic growth over the past 50 years but have also been the source of environmental problems. To restructure the national industrial base, the Korean government established a three-stage, 15-year plan to retrofit existing industrial complexes into EIPs. With strong government involvement, the institutional approach adopted in the first phase of the Korean EIP program successfully began to develop industrial symbiosis networks at five pilot sites.

In this paper, we conduct a comprehensive review of the first phase (2005–2010) of the Korean National EIP Development Program. The main objectives of this review are twofold: 1) to introduce the Korean approach to industrial symbiosis development and 2) to examine why the Korean approach has worked by analyzing its successes and limiting factors. For the first objective, we examine what drove the emergence of the EIP program within the larger context of Korea’s industrial development and then present the overall Korean EIP approach: its overarching framework, pilot sites, organizational structure, and strategies for project development. We also present the achievements of the first phase to show the scale of project development and the economic and environmental benefits generated during the first phase. We did not conduct a detailed analysis to understand the patterns of the program’s achievements, which will be the subject of future studies. We further examine program successes and limiting factors from technical, economic, legal/regulatory, and social perspectives to discern what made the Korean EIP approach effective in developing industrial symbiosis and how it can be improved. Finally, we conclude by summarizing the key characteristics of the Korean EIP approach.
Table 1

<table>
<thead>
<tr>
<th>Classification</th>
<th>Energy consumption (1000 toe/yr)</th>
<th>Waste generation (Kt/yr)</th>
<th>GHG emissions (Mt CO₂-eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National level (A)</td>
<td>Coal 22,311, Petroleum 96,718, Natural gas 17,811, Electricity 28,588, Other 3889</td>
<td>Waste generation 103,768</td>
<td>GHG emissions 569.5</td>
</tr>
<tr>
<td>Industrial sector (B)</td>
<td>Coal 21,237, Petroleum 50,905, Natural gas 4656, Electricity 14,346, Other 3222</td>
<td>Waste generation 44,126</td>
<td>GHG emissions 547.4</td>
</tr>
<tr>
<td>B/A</td>
<td>95%</td>
<td>53%</td>
<td>26%</td>
</tr>
</tbody>
</table>

(Table 1), which causes multiple types of pollution and generates long-term damage. Communities around industrial complexes formed the “National alliance for reforming industrial complex policy and enhancing environmental quality” in February 2002 (KFEM, 2002), reflecting the seriousness of the environmental problems. Early and traditional approaches to managing environmental problems, in response to stricter environmental regulations imposed by the Ministry of Environment (MOE), include the installation of environmental infrastructure such as air pollution prevention facilities and industrial waste treatment facilities. However, end-of-the-pipe approaches are economically inefficient and environmentally ineffective in preventing pollution and responding to resource scarcity (Choi, 2002; Yoo et al., 2004). It is also extremely difficult to track the sources and causes of environmental damage within industrial complexes and thus to determine who should be responsible for the cleanup (Lee et al., 2004). Because industrial complexes have complicated environmental problems of their own, the country needed to develop environmental criteria and management systems specifically for industrial complexes (Cho, 2002).

Meanwhile, after the Rio Earth Summit in 1992, the Ministry of Commerce, Industry, and Energy (MOCIE) adopted a comprehensive approach based on the concepts of cleaner production (CP) and industrial ecology to enhance the performance and competitiveness of industry while minimizing its environmental problems. In December 1995, MOCIE enacted the “Act To Promote Environmentally Friendly Industrial Structure (APEFIS)” and established an institutional system for CP and an environmental management system (EMS) based on ISO 14001 (Park et al., 2008). One program established under APEFIS promoted CP technology development and dissemination, which is notable: the adoption of CP began not only at an individual facility level, but also on the industrial complex or regional scale. APEFIS thus represents a fundamental approach that transforms the whole industrial structure to generate much larger benefits than applying CP strategies only to individual facilities. Given the need to repurpose an aged industrial base from the 1960s and improve environmental performance, this CP policy evolved into the idea of EIP development to holistically redesign and transform entire industrial complexes.

3. The evolution of the Korean EIP program

Because the need to transform the industrial base into EIPs exists on a national scale, the Korean government made a deliberate and conscious effort to develop industrial symbiosis. To make the EIP program successful, plan development began with a thorough study of the strengths, weaknesses, opportunities and threats (SWOT) in Korean industrial complexes. Based on that SWOT analysis, Korea developed its own approach to industrial symbiosis development. In this section, we first present the results of the SWOT analysis to define contextual factors and show how those results were reflected in the overarching approach, the master plan, pilot sites, organizational structure, and project development strategies of the Korean EIP program. We also show how the original plan for Korean EIPs changed and evolved during implementation.

3.1. Planning the overarching approach to industrial symbiosis based on the SWOT analysis

In October 2003, responding to the growing requests for industrial restructuring, MOCIE, currently known as the Ministry of Trade, Industry, and Energy (MOTIE), established the strategies for innovative sustainable industrial development that became the backbone of the National EIP Program. At that time, the Korean National Cleaner Production Center (KNCPC) was put in charge of developing a master plan for EIP development (KNCPC, 2004). To do so, KNCPC first conducted detailed reviews of international initiatives/programs for industrial symbiosis and consulted with Indigo Development and other international experts. To devise an EIP approach, considering Korea’s unique domestic context, instead of replicating strategies from other international industrial symbiosis initiatives, KNCPC conducted a SWOT analysis of the internal and external environments for industrial parks in Korea, as shown in Table 2.

The SWOT analysis showed that Korea’s agglomerated and diverse industrial base, matured since the 1960s, seemed to provide ample opportunities for industrial symbiosis. Proximity among industries can reduce transportation and transaction costs for industrial symbiosis, and diversity in industrial composition can provide increased opportunities for input–output matching. Such a technically conducive environment provided the basis for Korea’s vision of establishing a national EIP network. Korea also has a certain level of regulatory and institutional capability to promote its EIP program because of its existing policy on CP and innovative sustainable industrial cluster development. With that foundation, Korea aimed to enhance integration among its existing programs and improve its institutional structure. Because it is the public vision that transforms Korea’s industrial base into EIPs, the Korean government set up a scheme for financial support in the form of research funding. The intention was to provide economic incentives for industries to participate in feasibility studies and thereby draw further private investments in scaling-up the industrial symbiosis projects of the EIP program. Additionally, evaluation mechanisms for granting financial support promoted more feasible and competitive projects.

On the other hand, one of the major weaknesses found in the SWOT analysis was a lack of expertise and business awareness about industrial symbiosis. To bridge that gap, the Korean EIP program established regional EIP centers to provide overall consulting services on, for example, industrial symbiosis and the technical details required to conduct a feasibility study. EIP centers worked with “coordinators”, a group of local experts, to best consider local situations using local knowledge. They also operated eco-forums, a space for networking and information sharing among businesses. To build capacity, KNCPC and the Korea Industrial Complex Corporation (KICOX) hosted various training programs, conferences, and workshops on EIP strategy and implementation for the staff of the EIP centers. Most capacity building activities were advertised through central and local media, such as newspapers, radio, and TV programs. Broadly, the Korean EIP program adopted a stage-based evolutionary approach that began with experimentation through pilot projects and aims to scale-up the efforts through continuous learning and dissemination.
3.2. The EIP master plan

In October 2003, MOCIE announced a 15-year master plan for Korean EIP development. This plan was slightly modified when the EIP program was initiated under the leadership of KNCPC, a non-profit research organization that develops sustainable industrial development policies based on CP. However, the projects previously developed by KNCPC were mainly research-focused and related to topics such as CP technology development, dissemination, and capacity building, which raised concerns about whether they could encourage the active participation of businesses and thereby lead to the actual development of resource-sharing networks. The plan by KNCPC failed to get approval from MOCIE and could not secure the planned budget, which was about 810 million dollars for the entire 15-year program (KNCPC, 2004).

In December 2006, to encourage business participation and promote the development of resource-sharing networks, the authority for project management was transferred to KICOX, a semi-governmental body that manages national industrial complexes in Korea (KICOX and RIST, 2007). The move also integrated the EIP program with KICOX’s other policies on industrial complexes. KICOX placed more focus on developing and implementing resource-sharing industrial symbiosis projects than on R&D-type

| Table 3 | Evolution of the Korean EIP master plan. |
|---|---|---|
| **First phase** | **Second phase** | **Third phase** |

*ICs: industrial complexes.*
technology projects. Accordingly, the program’s vision and approach were revised. Table 3 shows the evolution of the EIP master plan according to the changes in program authority.

According to the EIP master plan finalized by KICOX, the 15-year initiative is divided into three phases: 1) the first phase (November 2005–May 2010) aimed to establish the foundation of the program through experimentation with five pilot industrial complexes, 2) the second phase (June 2010–December 2014) was the period of network expansion and focused on expanding the network of physical exchanges by disseminating knowledge and experience to industrial complexes connected to the pilot sites in a hub-and-spoke type of network, and 3) the third phase (January 2015–December 2019) aims to complete the national EIP network and establish Korea’s own EIP model based on lessons learned from the previous phases.

3.3. Pilot sites

Upon the announcement of the EIP master plan, KNCPC held several information sessions nationwide and called for applications for pilot project planning. Six industrial complexes applied and submitted their EIP plan for the first phase after one year of planning. After a careful review of the six pilot EIP plans, three areas (Pohang, Yeosu, and Ulsan Mipo-Onsan) were designated as the first set of pilot sites in October 2005. The remaining three sites improved and resubmitted their plans, and two of them (Banwol-Sihwa and Cheongju) were additionally chosen in February 2006. These demonstration sites comprise seven industrial complexes that are diverse in terms of location, industrial composition, scale, and age (Table 4).

The Banwol national industrial complex contains many small- and medium-sized enterprises. The Banwol and Sihwa industrial complexes were both established in 1977 to relocate facilities from the Seoul metropolitan area. The Ulsan-Mipo and Onsan industrial complexes contain diverse heavy industries, including petrochemicals, automobiles, and shipbuilding, representing multi-sector industrial complexes. The Yeosu national industrial complex is a petrochemical industry complex in a large coastal area. The Pohang national industrial complex is a single-industry complex for steel and its relevant industries along the supply chain. The Cheongju regional industrial complex includes electrical/electronic, machinery, petrochemical, and high-tech industries and focuses on promoting high-tech industries in its region.

3.4. Organizational structure

Fig. 1 shows the organizational structure after the change of supervisory body from KNCPC to KICOX. As a project executive

<table>
<thead>
<tr>
<th>Area</th>
<th>Industrial complex</th>
<th>Date established</th>
<th>Land area (km²)</th>
<th>No. of companies</th>
<th>Companies in operation</th>
<th>Production (billion US$)</th>
<th>Export (billion US$)</th>
<th>Industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyeonggi</td>
<td>Banwol-Sihwa</td>
<td>April 22</td>
<td>15.4</td>
<td>2567</td>
<td>2487</td>
<td>20.7</td>
<td>4.0</td>
<td>Machinery, electrical/electronic, petrochemical, textile</td>
</tr>
<tr>
<td>Ulsan</td>
<td>Ulsan Mipo-Onsan</td>
<td>January 27</td>
<td>46.2</td>
<td>629</td>
<td>557</td>
<td>73.8</td>
<td>36.2</td>
<td>Machinery, steel, chemical</td>
</tr>
<tr>
<td>Yeosu</td>
<td>Yeosu</td>
<td>April 01</td>
<td>17.3</td>
<td>232</td>
<td>194</td>
<td>18.5</td>
<td>9.1</td>
<td>Refinery, non-metals, pulp and paper</td>
</tr>
<tr>
<td>Pohang</td>
<td>Pohang</td>
<td>April 01</td>
<td>13.2</td>
<td>208</td>
<td>198</td>
<td>14.3</td>
<td>2.6</td>
<td>Steel, metals</td>
</tr>
<tr>
<td>Cheongju</td>
<td>Cheongju</td>
<td>June 23</td>
<td>4.1</td>
<td>241</td>
<td>233</td>
<td>7.5</td>
<td>3.9</td>
<td>Electrical/electronic, machinery, petrochemical, high-tech</td>
</tr>
</tbody>
</table>

Fig. 1. Organizational structure of the Korean EIP program.
body, KICOX is in charge of the overall planning, budgeting, approval of project proposals, and managing relationships with other governmental departments and relevant organizations. Affiliated with KICOX, five regional EIP centers administer the overall process of project development: from devising strategies based on local contexts to facilitating the development of project ideas by organizing forums and meetings, providing support for proposal writing, providing follow-up activities for on-going projects, and cooperating with local governments and relevant organizations. Each regional EIP center works with an advisory board — composed of representatives from local government, academia, and industry — that conducts proposal reviews and provides consultation for the overall direction of the regional programs. All the projects approved for implementation at a regional center are evaluated monthly by the assessment committee, composed of experts in the relevant areas.

3.5. Strategies for industrial symbiosis project development

Fig. 2 shows the overall process of project development. It begins with the formulation of project ideas, which is often performed by regional EIP centers (top-down) but can also be proposed by local actors, such as universities, research institutes, or participating businesses (bottom-up). The ideas are developed into project proposals for feasibility research, which are then submitted to KICOX and evaluated by the project assessment committee. KICOX set up quantitative targets for the economic and environmental benefits to be achieved based on the information presented in the proposals.¹ Depending on the assessment results, up to 75% of the necessary funding is provided by MOTIE; the rest is provided by the local government and participating companies (minimum 10%). After project implementation is complete, KICOX performs a final evaluation to determine whether the project has actually achieved the economic and environmental benefits anticipated in the proposal and determines the amount of technology fees (20—40% of government funding) to be paid back to MOTIE.

To identify industrial symbiosis projects, regional EIP centers use three strategies: 1) construction of a resource database, 2) organization of forums, and 3) appointment of coordinators. To develop resource-sharing networks through input—output matching, all the input and output resources in a region need to be investigated. Regional EIP centers build central databases not only for material resources but also for organizational, human, and infrastructure resources available in their region by conducting surveys and compiling environmental statistics from governmental and research organizations and data from project reports on a regular basis. However, those databases provide technical and quantitative details without considering actual facility conditions or other relevant contexts. To complement them, regional EIP centers organize forums to share more contextual information through stakeholder networking and therefore explore potential resource-sharing opportunities more fully. During the first phase, 27 forums were organized by type of materials (e.g., water/wastewater, energy, by-products) and type of industry (e.g., petrochemical, steel, semi-conductor), and they involved 969 participants and examined 113 project ideas. After the forums provide a space to identify potential project items, coordinators provide consultation for the follow-up processes, such as reviewing project feasibility, identifying companies with a demand, addressing regulatory issues, and securing funding. During the first phase of the EIP program, 51 coordinators were appointed, mostly retired managers and technical experts from local industries. The regional EIP centers adopted and combined the three strategies depending on the project being developed.

4. Achievements of the first phase of the EIP program

During the first phase, between 2005 and 2010, the Korean EIP program developed 116 projects at five pilot sites and seven industrial complexes. As of 2013, 47 projects had been successfully
implemented, generating considerable economic and environmental benefits. In this section, we present the achievements of the first-phase EIP program with regard to two aspects: 1) the number of projects developed and implemented over time and across pilot sites and 2) economic and environmental performance. We do this to judge the effectiveness of the Korean EIP approach in terms of the number of implemented projects and to understand the scale of the economic and environmental benefits generated from industrial symbiosis development. Our assessment of economic and environmental performance is based on information reported to KICOX at the moment of project completion. All quantification was done in a consistent manner based on standard methods provided by KICOX.

4.1. Project development

Fig. 3 shows the number of projects authorized for implementation and the number in operation after implementation over a nine-year period. During the first phase of the Korean EIP program, 175 projects were developed, and 116 of them were authorized for implementation. Of those 116 projects, 68 involved by-product reuse, 21 involved various types of energy use (e.g., use of residual heat from waste incineration or anaerobic digestion, heat recovery from by-products), and eight were about wastewater reuse. The other 19 projects were for other purposes, such as CP technology development, CP process assessment, or the establishment of EMS. Those 19 projects were developed...
during the first year when KNPC was in charge of the EIP program. KICOX suspended their implementation because they were considered unfit for the program goals, which are to promote and establish a resource-sharing network. From the second year, resource-sharing projects for the reuse of by-products, waste energy, and wastewater, were actively developed and supported. Overall, the number of projects authorized for implementation increased over time except in the fourth year, when the project period was shorter than other years.

Among the 116 projects, 47 were in operation as of 2013. Of those 47 projects, 14 began operation during the first phase of the EIP program, and the other 33 began operation in the second phase (Fig. 3). Most projects were completed within a year, but the completion of some projects took up to four years. A project that requires construction of appropriate infrastructure, such as pipelines, or a project that involves any change or expansion of production lines takes more time than a project that does not require substantial changes to existing processes. Complications in securing funding sources, completing negotiations (e.g., for the allocation of investment and benefits), and resolving regulatory issues (e.g., getting an approval or permit) are other reasons for delayed project implementation.

According to Fig. 4, the number of projects implemented and in operation varied across the five pilot sites, possibly due to a combination of diverse factors such as industrial composition, industry size, scale of the region, social relations, and the capacities of the EIP center and stakeholders. What is more important to note is that all five pilot sites developed industrial symbiosis networks, although to varying degrees, despite vastly different conditions. That could imply that the common institutional approach designed and adopted in the first experimental phase of the Korean EIP program can serve as the first general approach to developing industrial symbiosis in any industrial park or region.

4.2. Economic and environmental performance

The essence of industrial symbiosis lies in the economic and environmental benefits it generates. For governments, those benefits are also important measures to evaluate the success of individual projects. To examine the scale of benefits generated through the first phase of the Korean EIP program, we analyzed the economic and environmental performance of all 47 projects established and in operation as of 2013. We calculated economic performance as the difference in the sum of two components before and after the industrial symbiosis was implemented: 1) costs saved in resource procurement, operations, and environmental/waste management by replacing virgin materials with by-products and 2) net revenue generated by selling by-products. In total, the 47 projects generated 189 million US dollars of economic benefits, which is the sum of 97 million dollars of cost reduction and 92 million dollars of revenue generation. On average, energy projects tended to generate larger benefits than by-product projects because of their larger scale. However, when total benefits were compared with initial investment (i.e., the sum of government support and private investment), the return on investment (ROI) from energy projects was smaller than that from by-product projects (110% versus 577%). This resonates with the observation that compared to by-product projects, energy projects require more upfront investment in the installation of necessary equipment or pipelines, which increases the implementation time and decreases the rate of return. On the contrary, by-product projects tend to have high rates of return, sometimes reaching up to 2000 or 3000%. In nine by-product cases, the project generated considerable benefits without any investment: for example, heat transfer salt that reached its end-of-life after use in petrochemical processes was easily repurposed as a useful descaling salt for annealing and pickling stainless steel, and a

![Economic benefit (million USD)](image)

Fig. 5. Economic benefits from 47 projects, arranged by project type and amount of benefit: cost reductions (blue bars, left axis), revenue generated (red bars, left axis), and return on investment (black dots, right axis). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
waste organic solvent was used directly as an ingredient for paint without additional process or treatment. Wastewater projects showed even higher ROIs than by-product projects: the profit of wastewater projects mostly came from savings in wastewater treatment cost, which tended to be relatively high because of materials that are difficult to degrade, as well as savings in procurement costs by reusing materials recovered from wastewater (Fig. 5).

Fig. 6 presents the relative size of economic benefits by government funding. This indicator represents the top-down nature of the Korean EIP program. The program produced economic benefits 10 to 100 times greater than the amount of government funding (except for one project with a ratio of 470%, which was excluded from the figure), which enabled continuous support from the government. Energy and wastewater projects showed higher returns on government support than by-product projects: by-product projects were driven more by government funding in developing new ideas for industrial symbiosis but used existing facilities and technologies, whereas energy and wastewater projects drew sufficient private investments to construct the necessary new facilities.

We evaluated the environmental performance of the EIP project in terms of direct reduction of energy consumption as well as reductions in the generation of waste, wastewater, and emissions achieved through industrial symbiosis implementation. This is likely a conservative proxy for the total environmental impact including indirect effects. During the first phase, 47 projects reduced waste by 477,633 metric tons, wastewater by 110,032 metric tons, energy by 176,781 toe, and greenhouse gases by 668,198 metric tons CO2-eq. This is equivalent to 0.83% of waste generation, 0.008% of wastewater generation (NIER, 2014), 0.14% of energy consumption in 2012 (KEEI, 2013), and 0.10% of greenhouse gas emissions from industrial activities in Korea in 2011 (GIR, 2014).

The environmental benefits of each project vary considerably, particularly in the case of by-product projects (Fig. 7). The highest level of by-product reuse involved more than one million metric tons of by-product reduction per year by using molten desulfurization slag from steel-making as a concrete admixture. On average, 15,515 metric tons of by-products per year were reused in each of the 47 projects during the first phase. In the case of energy, 20,000 to 30,000 toe/year of energy reduction was most typical, though 40,000 to 50,000 toe/year of energy reduction was observed in a steam-sharing project in Ulsan. In each wastewater project, fewer than 50,000 metric tons of wastewater were reduced per year.

5. Successes and limiting factors in the first-phase EIP program

In this section, we discuss how the first-phase Korean EIP program successfully implemented industrial symbiosis projects by examining technical, economic, legal/regulatory, and social factors to expose important drivers for further industrial symbiosis development in Korea and elsewhere. We also discuss limitations found in the pilot experimentation and propose advanced strategies for the second phase, which aims to scale-up eco-industrial development efforts.

5.1. Technical factors

As seen in the SWOT analysis, Korea’s agglomerated and diverse industrial structure provided a great base for industrial symbiosis development. The five demonstration sites from the first phase in particular showed diverse technical potential for industrial symbiosis development. Ulsan-Mipo and Onsan were the leading industrial complexes during the first phase program with more than 800 diverse and large-scale industries. The Yeosu and Pohang national industrial complexes are single-industry-dominated complexes, which could develop specialized industrial symbiosis networks among industries along the supply chain.

With great technical potential for industrial symbiosis, the regional EIP centers established various databases of material, organizational, human, and infrastructure resources at the five pilot sites. As a result, the first-phase EIP program established 17,600 databases for materials, 4000 databases for industrial sites, and
7100 databases for relevant organizations and human and infrastructure resources. These were a great starting resource to develop potential industrial symbiosis projects, especially during the first phase when low-hanging opportunities were widely available.

5.2. Economic factors

Along with environmental benefits, economic benefits are a central feature of industrial symbiosis and the main motivation for businesses to participate. However, positive economic gains from waste reuse often fall outside of business considerations and are perceived as negligible compared to the size of profits from the main businesses. In the Korean EIP approach, the government did not intend for its financial support to provide all necessary investments to realize industrial symbiosis. Instead, government funds were intended to help businesses examine potential economic benefits at the feasibility study phase. That support motivated industries to conduct feasibility studies and drew private investments later when businesses realized the scale of the economic benefits offered by a project. KICOX evaluated project proposals and strategically choose more feasible and competitive projects with larger expected outcomes. Thus, a positive way to use government financial support is as leverage to draw private investment and scale-up industrial symbiosis projects, although heavy government involvement and funding can discourage voluntary participation by businesses, as seen in other cases (Heeres et al., 2004).

In the first phase, government financial support had a ceiling of 0.3 billion Korean won. But as the scale of EIP development increases in the second phase, additional financial support could be necessary for large-scale projects that require large upfront investment, such as projects that involve a large number of businesses across different industrial clusters or the construction of large-scale infrastructure. According to the benefits accrued, government funding could increase to 0.5 billion Korean won in the second phase.

5.3. Legal and regulatory factors

Legal and regulatory instruments have been frequently cited as a barrier to industrial symbiosis: strict, fixed, inconsistent, or uncertain regulatory requirements imposed on the storage and transportation of reusable waste materials can limit or hinder the development of industrial symbiosis projects (Gibbs and Deutz, 2007; van Beers et al., 2007). From the beginning of the EIP program, KICOX, in collaboration with the Korean government, focused on establishing appropriate legal and regulatory systems to support and promote EIP projects. As a basis of the EIP program, the Transition to Environment-friendly Industrial Structure Act was amended in 2006 to provide an overarching legal framework for the activities of the regional EIP centers. In particular, it empowered the regional EIP centers to compile the necessary statistics from central and local government bodies and to collect industry data through facility visits and surveys. In August 2009, an amendment to the Industrial Cluster Development and Factory Establishment Act (KICOX and RIST, 2010) allowed environmental industries that process and recycle by-products and residual heat (i.e., scavengers and decomposers) to be located within an industrial complex. Before that amendment, those industries were classified as service or ancillary facilities and had limited ability to move into industrial complexes, which was hindering the development of resource-sharing networks.

Despite these advances during the first phase, waste regulation remains a major issue for EIP development in Korea. The uses of industrial by-products are regulated and limited by the “Waste Control Act” (amended in 2007), even when recycling technologies are available and potential users are specified. In one project, the Waste Control Act limited the use of wastewater sludge (e.g., as a complementary fuel at a coal-fired power plant, soil amendment, land cover, or input material for plastic production), which was later deregulated through discussion and collaboration between KICOX and the MOE. In 2010, KICOX requested the deregulation of industrial by-products that can be reused, and efforts are under way to redefine waste and differentiate it from by-products. More importantly, as seen in the Kalundborg case (Jacobsen and Anderberg, 2005), a closer collaboration with regulatory bodies such as the MOE is required for the flexible application and adaptation of waste regulations on a case-by-case basis. That needs to be improved in the second phase.

Legal settings also hindered the development of resource-sharing networks across administrative boundaries even though potential business connections were in close proximity. For

![Fig. 7. Distribution of environmental effects according to project type and environmental impact category.](image-url)
that reason, EIP development in the first phase occurred only within the boundaries of the pilot industrial sites. To provide more opportunities for EIP development and increase connectivity across industrial complexes, the second phase will focus on building regional networks instead of networks within individual industrial complexes. Strategically, any industrial complex with a high potential for EIP development will be designed as the hub of a network with three or four neighboring complexes as spokes.

5.4. Social factors

The role of social factors has received increasing attention in the literature because the development and implementation of industrial symbiosis depends on social dynamics at both the inter-organizational and organizational levels. At an organizational level, the attitude, willingness, and workload of managers as well as the capability and culture of an organization is important in determining business participation in industrial symbiosis (Fichtner et al., 2005). Often, many issues act as a disincentive for businesses to participate in industrial symbiosis. For example, the development of a by-product reuse project could weaken or even remove the role of the waste department, which clearly discourages the assistance of waste department personnel. To address those barriers, the regional EIP centers help participating firms provide fair project benefits and recognize the personnel and department in charge of the project for their work and achievements. If necessary, the EIP centers help create a new unit for resource recovery and circulation so the role of the unit aligns with the goal of the EIP projects without loss of jobs.

At an inter-organizational level, industrial symbiosis and transaction of waste resources is governed by the extent of communication, sharing of tacit knowledge, development of trust, and willingness to cooperate (Ashton, 2008; Boons, 2004; Gibbs, 2003; Grant et al., 2010; Hewes and Lyons, 2008; Jacobsen, 2007). To mobilize the participation of various stakeholders in addition to business actors, regional EIP centers organized 27 forums for 969 stakeholders from businesses, universities, research institutes, and local governments (KICOX and RIST, 2010) as a way to promote communication, information sharing, and cooperation among them. The EIP centers also hired 51 local experts, such as business retirees and professors, as coordinators to help take advantage of local tacit knowledge in project development and implementation.

Facilitating participation was particularly difficult in the early phase of the EIP program. To address that behavioral roadblock, the Ulsan EIP center focused on developing the first successful project as a model case, a steam-sharing network between a city waste-to-energy incinerator and a chemical company (Park and Park, 2014). The success of that project and the sharing of its economic and environmental achievements increased the interest of other stakeholders in the region, generating trust about the EIP program and regional EIP center and therefore creating momentum for the EIP program. The steam-sharing model was diffused to other regions of Korea that contain incinerators and facilities that require steam energy.

KNCPC’s initial plan for the Korean EIP program did not envision the participation of local governments and communities. However, working with local governments and communities provides more opportunities and increased effectiveness for developing resource-sharing networks in a region, as seen in urban symbiosis projects in Japanese eco-towns (Van Berkel et al., 2009). To attract active participation from local governments during the first phase, KICOX encouraged local governments to provide financial support in the form of matching funds. However, because that was not mandatory, the regional EIP centers had to negotiate with local governments for every project, which was an exhausting and tedious process. Therefore, in the second phase, the rate of matching funds will be set at 20%, and the participation of local governments will be included as one of the factors in proposal evaluations.

6. Discussion: key characteristics of the Korean EIP approach

With a national need to enhance the performance and competitiveness of an aged industrial base, the Korean government established a three-stage, 15-year EIP program. During the first five years of pilot experimentation, between 2005 and 2010, the program produced significant economic and environmental benefits by developing and implementing 47 industrial symbiosis projects at five pilot sites. Economic benefits from cost savings and revenue generation reached 189 million US dollars, and environmental benefits in terms of greenhouse gas reductions already achieved 51% of the target set by Korea’s low-carbon green growth policy.

Those achievements were possible due to an effective institutional approach developed and adopted based on the results of a SWOT analysis. From the start, the Korean EIP approach adopted a top-down method, mostly represented by government financial and institutional supports. The government’s financial supports provided research funds only to conduct feasibility studies instead of providing all investments needed to realize industrial symbiosis projects. That was enough to mobilize business actors because they could see potential economic benefits or develop new business models. Depending on the size of the benefits, business actors often made further investments on their own after the government prioritized and selected the most feasible and competitive projects.

In addition to research funding, the Korean government provided additional institutional supports to project development and implementation in the form of dedicated experts and staff. Those people helped businesses through the entire process of project development, implementation, and operation: from brainstorming and evaluating ideas for industrial symbiosis (forums, feasibility studies, workshops, consulting services) to resolving any technical and regulatory issues during project development, negotiations, and monitoring (coordinators, networking). Without dedicated personnel, it might be difficult for businesses to do industrial symbiosis projects, which require extra work for side projects that are not in their main businesses. Those activities were primarily managed by the regional EIP centers. As local project execution hubs, the regional EIP centers support bottom-up participation from businesses and promote communication and cooperation among industries, local experts, research institutes, and governments. As more projects are developed and implemented, the regional EIP centers continue to gain trust and change how industrial symbiosis projects are perceived in their regional environments.

Thus, the key characteristic of the Korean EIP approach is the combination of top-down and bottom-up approaches. Governments not only provide research funds to mobilize businesses, but also provide support throughout project development and monitoring to select feasible low-hanging projects and maintain competitive outcomes. Also, any strategies, experience, and knowledge can be shared more effectively through regular conferences, workshops, and training programs. The key players in promoting voluntary bottom-up activities are the regional EIP centers, which bring together all relevant stakeholders and coordinate their needs through communication and sharing of tacit...
knowledge. In some sense, the regional EIP centers play the role of a local champion (Hewes and Lyons, 2008) or knowledge broker (von Malmberg, 2004).

During its first phase, the Korean EIP approach began to generate tangible industrial symbiosis outcomes at all five pilot sites, which have vastly different local conditions. This implies that it could be the first general approach to developing industrial symbiosis anywhere. However, application of this approach also requires fine tailoring and adjustments according to local contexts, which requires the development of tacit knowledge and the accumulation of experience.

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