Resources, Conservation & Recycling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea

Hyeong-Woo Kim[a,c], Liang Dong[a,b], Angelo Earvin Sy Choi[c,d,e], Minoru Fujii[a], Tsuyoshi Fujita[a], Hung-Suck Park[c,e,*]

[a] Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba-City, Ibaraki, 305-8506, Japan
[b] Institute of Environmental Studies (CML), Leiden University, Leiden, The Netherlands
[c] Center for Clean Technology and Resource Recycling, University of Ulsan, 93 Daehakro, Ulsan, 680-749, South Korea
[d] Chemical Engineering Department, De La Salle University, 2401 Taft Ave, Manila, 0922, Philippines
[e] Department of Civil and Environmental Engineering, University of Ulsan, 93 Daehakro, Nam-gu, 44610, Ulsan, South Korea

ARTICLE INFO

Keywords:
District heating
Eco-industrial park
Industrial symbiosis
Low-grade waste heat
Urban symbiosis
Ulsan

ABSTRACT

Energy depletion and global climate change have stimulated the Korean government to strengthen energy saving and efficiency measures in all sectors. However, in industrial sector where huge energy is consumed, only small portions of the high-grade waste heat from industrial processes have been utilized by another process through industrial symbiosis networks in industrial park and large quantities of low-grade waste heat are mostly discharged into the environment. Through technological assessment of energy balance between waste heat source in industrial park and heat sink in industrial park and urban area, this study systematically develops an industrial-urban symbiosis (I-US) and conducts a co-benefit analysis for 4 scenarios. Based on the investigation on the energy utilization status of Ulsan, the scenarios for potential I-US networks are evaluated. For the supply and demand side, potential energy sources and sinks are estimated at 49,321 and 15,424 TJ/yr, respectively, noting that the demand side considered four scenarios based on the local condition analysis. Through these scenarios for the energy symbiosis networks; a reduction of 243,396 ton/yr CO_2 emission and 48 million US Dollar/yr fuel cost were achieved. Due to a large transition cost for a district heating system, I-US public private partnership business model is highly recommended to attract long-term investment and institutional incentives of carbon credit and energy service companies fund are conducive to put these scenarios into practice.

1. Introduction

Industrial parks have fueled the rapid economic development and urbanization of Korea since 1962. Industrial parks, as the interface infrastructure between the resource consumption and products production, have posed various challenges and opportunities for economic, environmental and social issues at urban scale in Korea and many developing countries. To address these emerging challenges, the concept of a circular economy that applies industrial symbiosis (IS) and eco-industrial park (EIP, as a practice of IS), which focuses on the cascading and circular networking (those with geographical proximity) of resources, energy and wastes in industrial park, has been established and under global practice since early 2000 (Basu and Van Zyl, 2006; Fet, 2001; Hamner, 1996; Organisation for Economic Cooperation and Development, 2009). The industrial organization patterns the EIP which follows a circular flow model in a “resources-products-renewable resources” that serves as a major player in sustainable development (Zeng et al., 2017).

Through National EIP initiative, Ulsan city have benefited from 14 energy symbiosis networks of the high-grade heat to reduce the energy consumption and carbon emission reduction in the Onsan and Ulsan-Mipo national industrial parks (Table 1).

The energy sources and sinks of these 14 IS networks are shown in Figs. 1 and 2. The energy sources of 5 networks (#1: Yoosung to Hankuk paper, #3: Bumwoo to Korea petrochemical or GS Eco metal, #6: Sung-Am MWIF to Hyosung yongyeon #2 plant and KP chemical to Korea PTG, #8: Hyundai heavy industry to Hyundai hysco and Hyundai motors, and #12: Sung-Am MWIF to Hyosung yongyeon #2 plant to Hyosung yongyeon #1 plant, SKC) are the heat produced from waste incineration, and the 7 networks (#2: Korea zinc to Hankuk paper, #4: Korea zinc to Hanwon precision chemical or Yeongkwang, #7: Hansol EME to Korea PTG and Korea PTG to SKC, #9: Aekyung Petrochemical to Hanju to Evonik headwaters, #11: Taekwang petrochemical #1 to SK energy to Hyosung Ulsan plant, #13: SK chemical to Hyosung Ulsan, SK energy, Taekwang petrochemical #1, and #14 Lotte chemical to

* Corresponding author at: Department of Civil and Environmental Engineering, University of Ulsan, 93 Daehakro, Nam-gu, 44610, Ulsan, South Korea.
E-mail address: parkhs@ulsan.ac.kr (H.-S. Park).

http://dx.doi.org/10.1016/j.resconrec.2017.09.027
Received 31 January 2017; Received in revised form 23 August 2017; Accepted 26 September 2017
0921-3449/

Table 1
Economic and environmental impacts of the 14 IS networks in Ulsan.

Energy IS	Investment (Million US Dollar)	Economic benefit (Million US Dollar/yr)			Environmental benefit (tCO_2/year, toe/yr)	
		Cost reduction	Revenue	Sum	GHGs	Energy
1	0.9	28.5	10.0	38.5	12,491.0	3,893.3
2	21.0	32.1	33.9	66.0	63,642.8	26,848.8
3	10.0	–	55.6	55.6	25,084.0	8,278.0
4	1.7	16.7	–	16.7	14,572.0	5,564.8
5	1.2	–	9.0	9.0	4,757.0	2,037.0
6	5.0	32.0	39.0	71.0	60,476.0	18,850.0
7	14.0	40.1	–	40.1	34,906.7	10,880.0
8	6.2	32.0	–	32.0	10,188.0	6,024.0
9	1.5	10.8	17.4	28.2	33,094.0	8,881.0
10	1.0	4.7	0.5	5.2	303.6	146.0
11	6.0	30.0	62.0	92.0	50,396.0	16,716.0
12	8.2	64.0	83.0	147.0	39,427.0	18,960.0
13	66.7	18.0	–	18.0	100,000.0	46,317.0
14	2.9	11.4	12.8	24.3	37,327.0	9,254.5
Sum	146.3	320.3	323.2	643.6	486,665.1	136,333.4

Reference: Eco-industrial park development program in Ulsan: 1–5 year report of the 1st and 2nd phases (2005–2014).

Fig. 1. Status of the energy IS at the Onsan national industrial park in Ulsan (red: heat source, blue: heat sink).

Eastman) are the heat produced from the processes like petrochemical, chemical, smelting, and other processes. Network #5 (Onsan organic waste biogas facility to Hankuk paper) is the biogas produced from the digestion process where the organic waste liquids like livestock wastewater and food waste are treated. The steam in this network operates at a medium pressure by using the biogas that is fed into a nearby company as the energy source for the process. Network #10 (Hyosung Ulsan plant to Hyosung Ulsan plant) is the digestion gas produced from the anaerobic process where the organic sludge and waste liquid are treated.

However, energy lost in this type of industrial waste heat is reported to be prevalent worldwide. In China, 50% of the energy used in industries are wasted in the form of low-grade waste heat (Fang et al., 2015). In the United States, 20–50% of the energy consumed in mineral manufacturing are lost as waste heat (Johnson et al., 2008). In Turkey, 51% of the processed heat from the cement plant are wasted (Sogut et al., 2010).

To date, large quantities of low-grade waste heat, between 30 and 100 °C, are discharged into the environment by water evaporation in the industrial processes (Svensson et al., 2008; Zhang and Akiyama, 2009). Some sources of waste heat include chemical waste, waste process liquid, gaseous exhaust, and cooling media (Fang et al., 2013).

In the aspect of industrial waste heat utilization at different temperature zones, various technologies are used in the industrial and urban sectors. The supplying companies in the industrial sector produces specific quality of steam for their processes and various level of consequent waste heat. The waste heat generated is then used towards other individual companies as an energy source. The produced steam goes to the steam supply system of the demanding companies through a pipeline. For the urban sector, waste heat is utilized differently in heating and cooling purposes. Through a central heating system, the waste heat generated from each company flows to the heat management center for proper heat control. The collected heat is then supplied to the heating system of the apartment complexes or commercial building in a heat exchanger. For further improvement in the heating system, the existing individual heating system should be changed to a central heating system in order to maximize the recycling of waste heat in the central heating system mode. In the aspect of cooling, the collected heat is supplied to the cooling system of the apartment complexes or the commercial buildings going through an absorption refrigerator or a centrifugal refrigerator.

For an effective the utilization of low grade waste heat, the consideration of an urban symbiosis (US) is essential. The US as an extended concept of the IS represents an opportunity arising from a geographic proximity in the industrial and urban areas (Chen et al., 2011). The development of an industrial-urban symbiosis (I-US) can optimize the regional energy network through its sharing of infrastructures and resources (Sun et al., 2016). The I-US networks using high and low-grade waste heat is an effective measure to reduce the energy consumption and greenhouse gas (GHG) emissions. In the situation that the global society is making an effort to mitigate global warming and the energy crisis, the system design for an I-US of high and low-grade waste heat could be an important regional measure which may be sufficiently worth to consider. Fig. 3 illustrates the representation of an I-US.

A conceptual framework (Fig. 3a) of the I-US shows that heat from the industrial sector consist of a circulation of low, medium and high-pressure steam through heat pinch for energy optimization. The combustible waste and by-product gas in the industrial sector are utilized to generate electricity. On the other hand, the waste heat from the industrial sector is supplied towards a heat management center and this is carried over as a district heat supply in the urban sector. At the urban sector, the combustible municipal waste is sent through the incinerator plant and its waste thermal heat are sent back in the industrial sector. In the incinerator plant, incineration heat is supplied towards the industrial sector. The biodegradable organic waste also can be digested to produce methane, which can be used as a fuel source in industrial sector and used to produce electricity.

Fig. 3b illustrates the technical concept of the I-US using low grade waste heat in an industrial park. The industrial waste heat is processed at the 1st heat exchanger at 120 °C and goes to a 2nd heat exchanger in the heat management center at 95–115 °C. After this, heat around 95 °C is going to through pressure pump (5–7 kg/m^2) in a supply header. The waste heat would go to a heat exchanger of the urban area and be pumped at 65 ± 5 °C to the public, office buildings and apartment. The waste heat at 50 ± 5 °C from the urban area will go through a heat exchanger to a return header in the pressurization facility at 3–4 kg/m^2 straight to a recycle pump. The waste heat is returned to the 1st exchanger at 62 ± 3 °C and comes out at 93 °C as processed waste heat.

As the high grade energy network in Ulsan city have already shown