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Industrial symbiosis and urban areas: a systematic literature review and future research directions

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Abstract

This paper proposes a systematic literature review concerning the implementation of industrial symbiosis (IS) within urban areas, a concept that has been defined by the literature as "urban symbiosis" and "urban-industrial symbiosis", indifferently. 26 papers published between 2009 and 2018 are analyzed. This review is aimed at highlighting: (1) the specific research goals addressed; (2) the IS synergies currently implemented within urban areas; and (3) barriers and enablers to the implementation of IS within urban areas. Suggestions for future research are also proposed.

Keywords: industrial symbiosis; urban symbiosis; urban areas; circular economy; literature review.

1. Introduction

Actually, cities are responsible for huge environmental impacts in terms of resource and energy consumption, waste generation, and greenhouse gas (GHG) emissions (e.g., Grimm et al., 2008; Yang et al., 2018). However, the polluting role of cities is further critical if we consider the expected future trends: in fact, recent estimations preview that cities will use 80% of global energy by 2040 (Shell International BV, 2014) and will double waste production by 2025 (The World Bank, 2012). Industrial symbiosis (IS) applied at the urban level can be an effective strategy to make cities more environmentally sustainable (Van Berkel et al., 2009b).

IS refers to the use of industrial wastes as alternative inputs to production processes (Chertow, 2000). By implementing IS synergies, different companies can reduce the amounts of wastes landfilled and primary inputs used and create economic benefits simultaneously, because reducing their production costs (e.g., Jacobsen, 2006). In recent years, the literature has investigated the adoption of IS strategies within urban areas, i.e., synergies concerning the use of urban wastes as alternative raw materials and energy sources in industrial operations that conventionally do not accept wastes. The literature refers to these synergies as "IS at urban level" (e.g., Albino et al., 2015), "urban symbiosis" (e.g., Van Berkel et al., 2009b), and "urban-industrial symbiosis" (e.g., Ohnishi et al., 2017), indifferently. These synergies have been proved effective in reducing the amounts of wastes disposed of in landfills, the amounts of inputs used in industrial operations, and the amount of GHG emissions (e.g., Huang et al., 2016).

So far, the literature limited to present case studies with the aim to disclose IS synergies and highlight the economic and environmental benefits that can be created thanks to their adoption. However, these studies are highly case-specific and a comprehensive view of this practice is lacking. This paper aims at filling this gap by providing a systematic literature review on IS adopted within urban areas. In particular, the review is aimed at highlighting: (1) the specific research goals addressed; (2) the IS synergies currently implemented within urban areas; and (3) barriers and enablers to the implementation of IS within urban areas.

The paper is structured as follows. Section 2 describes the methodology adopted for this study. Section 3 shows the results of the literature review. Finally, Section 4 presents conclusions and suggestions for future research.

2. Methodology

The study is based on a bibliographic research conducted on 3rd May 2018. The first step was to collect papers. The data were retrieved from Scopus, an academic citation indexing and search service of Elsevier. The following research keywords have been applied to title, abstract, and keywords of papers: ["*Industrial symbiosis*" **AND** (*city* **OR** *cities* **OR** "*urban area**")] **OR** "*Urban symbiosis*". The analysis was restricted to papers published in English in international journals. As the result of the research, 80 papers were collected. A first post-processing of the literature data was operated aimed at excluding papers not relevant enough (e.g., papers where the IS within urban areas was not the main research topic but was only mentioned as a suggestion for future works). A second post-processing was carried out aimed at reducing the number of duplicated entities that occurred in the analysis. The final database is made of 26 papers.

3. Results

3.1 General insights

The 26 papers belonging to the final database are displayed in Table 1. They have been published between 2009 and 2018 in 13 journals (Table 2).

64 researchers were found among the authors of the analyzed papers. Fig. 1 shows the co-authorship map, where nodes denote researchers and two nodes are linked if the correspondent researchers co-authored at least one paper. In particular, the size of the node is proportional to the number of authored papers. A high level of connection among these researchers exists, meaning that the research is not fragmented. However, five isolated research groups can be noted, each of them authoring one paper. Eight case studies are described by the literature: four cases in China (Liuzhou, Jinan, Guiyang, Shenyang), three cases in Japan (Kawasaki, Shinchi Town, Tanegashima), and one in South Korea (Ulsan).

Table 1. Papers analyzed in the literature review.

Title	***Reference***
A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan	(Ohnishi et al., 2017)
A design of rural energy system by industrial symbiosis considering availability of regional resources	(Kanematsu et al., 2017)
Achieving carbon emission reduction through industrial & urban symbiosis: A case of Kawasaki	(H. Dong et al., 2014)
Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China	(Fang et al., 2017)
Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea	(Kim et al., 2018)
Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China	(Sun et al., 2017)
Eco-industrial networking for sustainable development: review of issues and development strategies	(Gibbs and Deutz, 2005)
Eco-industrial zones in the context of sustainability development of urban areas	(Sacirovic et al., 2018)
Effect of urban symbiosis development in China on GHG emissions reduction	(Huang et al., 2016)
Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city	(Ohnishi et al., 2018)
Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan	(Dong et al., 2013b)
Evaluation of innovative municipal solid waste management through urban symbiosis: A case study of Kawasaki	(Geng et al., 2010)
Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China	(Dong et al., 2017)
Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006	(Van Berkel et al., 2009b)
Industrial symbiosis as a countermeasure for resource dependent city: a case study of Guiyang, China	(Li et al., 2015)
Industrial symbiosis for a sustainable city: technical, economical and organizational issues	(Albino et al., 2015)
Innovative planning and evaluation system for district heating using waste heat considering spatial configuration: A case in Fukushima, Japan	(Dou et al., 2018b)
Low-carbon benefit of industrial symbiosis from a scope-3 perspective: A case study in China	(Li et al., 2017)
Possibility of developing low-carbon industries through urban symbiosis in Asian cities	(Fujii et al., 2016)
Promoting low-carbon city through industrial symbiosis: A case in China by applying HPIMO model	(Dong et al., 2013a)
Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan	(Van Berkel et al., 2009a)
Realizing CO2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki	(Hashimoto et al., 2010)
Strategies for sustainable development of industrial park in Ulsan, South Korea-From spontaneous evolution to systematic expansion of industrial symbiosis	(Park et al., 2008)
Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China	(Dong et al., 2016)
Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem	(Cao et al., 2017)
Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects	(L. Dong et al., 2014)

Table 2. Journals where the considered papers are published.

Journal	*Number of papers*	*Impact factor*	*H-index*
Journal of cleaner production	7 (29.62%)	5.651	132
Resources, conservation and recycling	5 (19.23%)	5.120	94
Ecological modelling	2 (7.69%)	2.507	132
Energy policy	2 (7.69%)	4.039	159
Journal of industrial ecology	2 (7.69%)	4.356	80
Advances in climate change research	1 (3.85%)	---	10
Applied ecology and environmental research	1 (3.85%)	---	23
Computer aided chemical engineering	1 (3.85%)	---	21
Ecological indicators	1 (3.85%)	3.983	84
Energy	1 (3.85%)	4.968	146
Environmental science and technology	1 (3.85%)	6.653	319
Journal of environmental management	1 (3.85%)	4.005	131
Procedia engineering	1 (3.85%)	---	40

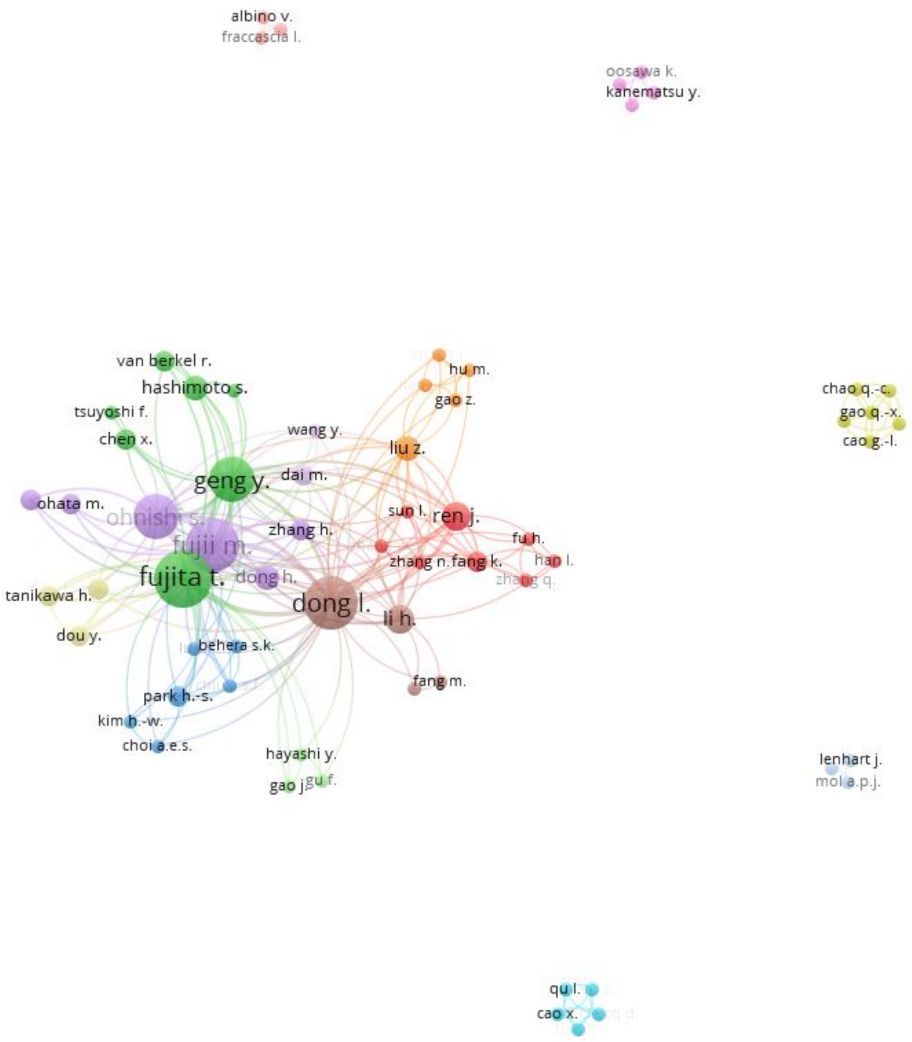

Fig. 1. Co-authorship map.

3.2 Literature overview

Five main topics can be highlighted: (1) description of case studies; (2) assessment of benefits created by IS; (3) methodological contributions; (4) factors affecting the implementation of IS; and (5) energy-based IS. They are presented as follows.

Description of case studies. The early-published papers are mainly descriptive, aimed at showing projects of IS in urban areas. Van Berkel et al. (2009b, p. 1545) first provide a formal definition for the concept of urban symbiosis, i.e., "the use of by-products (wastes) from cities (or urban areas) as alternative raw materials or energy source in industrial operations”. Then, they present Japan’s Eco-Town Program, which is aimed at creating economic and environmental benefits through implementing processes of urban symbiosis. For each city involved in the project, they highlight the investment required, the subsidies provided by the government, and the amounts of wastes diverted from landfill. Van Berkel et al. (2009a) focus on the city of Kawasaki: they describe the processes of urban symbiosis implemented within the framework of Japan’s Eco-Town Programme and assess the environmental and economic benefits created. Dong et al. (2013b) describe the symbiotic processes implemented in the two Chinese cities of Liuzhou and Jinan, highlighting the amounts of wastes saved from landfills and assessing the economic benefits created.

Assessment of benefits created by IS. Then, the literature focused on assessing the environmental and the economic benefits created by adopting the IS at the urban level. L. Dong et al. (2014) compute CO_2 emissions reduction potential under promoting IS projects in the two Chinese cities of Jinan and Liuzhou. Geng et al. (2010), Hashimoto et al. (2010), and H. Dong et al. (2014) compute the reduction in CO_2 emissions in Kawasaki by adopting the LCA approach. In addition to the emissions avoided by replacing inputs with wastes, they also consider the CO_2 emissions due to waste collection and pretreatment, as well as the emissions due to building new facilities. Dong et al. (2013a) propose an urban-level hybrid physical input and monetary output model, which covers physical energy inputs and air pollutants emissions, to assess the reduction in air pollutant emissions (i.e., CO_2, NO_x, SO_2) in Liuzhou thanks to the adoption of urban symbiosis. Li et al. (2015) present the symbiotic processes adopted in the city of Guyang and provide a quantitative assessment of the environmental benefits through a material flow analysis approach. They also compute the reduction in CO_2 emission thanks to the symbiotic processes. Huang et al. (2016) conduct a statistical analysis of the emissions reduction of CO_2 and CH_4 thanks to symbiotic processes in Chinese cities. Cao et al. (2017) show the symbiotic projects involving urban wastes that can be implemented by cement plants, evaluating their environmental and economic performance, identifying barriers in promotion, and proposing supportive policies.

Methodological contributions. Dong et al. (2016) analyze the environmental benefits created in the same city by adopting an integrated input-output and process LCA. Such a methodology has been also used to assess benefits created in Liuzhou (Dong et al., 2017) and Guiyang (Fang et al., 2017). Other methodologies have been proposed, aimed at computing environmental benefits of IS in urban areas, and tested for real cases: the Scope 3 CO_2 emissions (Kawasaki) (Li et al., 2017), an integrated material flows analysis (MFA) and emergy evaluation model (Liuzhou) (Sun et al., 2017), a combined material flow analysis (MFA), carbon footprint (CF) and emergy methods (Kawasaki) (Ohnishi et al., 2017).

Factors impacting on the implementation of IS. Chen et al. (2012) analyze how environmental benefits and operational performance of Eco-Towns can be affected by project scale (i.e., the amounts of wastes used as inputs), the recycling boundary, and types of waste. Fujii et al. (2016) examine the feasibility of urban symbiosis projects in three Asian cities: Kawasaki (Japan), Ulsan (South Korea), and Shenyang (China). For each city, the potential for reduction in CO_2 emissions as well as the costs of promoting hybrid industries are evaluated. The study discuss the factors able to affect the cost-effectiveness of symbiotic projects, including the spatial density of waste generation, the waste composition, the relative labor cost for collection and pre-treatment of wastes compared with construction cost of an incinerator and avoided costs through product and fossil resource substitution, and the willingness of citizens to separate wastes. Lenhart et al. (2015) investigate how urban actors, mainly the local authorities, can facilitate the implementation of IS projects in urban areas by analyzing the case of Rotterdam Energy Approach and Planning. In particular, they focus on geographic boundaries, local collaboration and partnership among actors, and government policy intervention. Albino et al. (2015) propose a theoretical framework highlighting the main urban processes responsible for organic waste generation and discuss how urban characteristics might the implementation of IS projects involving these wastes.

Energy-based IS. Some papers focus on energy production from urban wastes. Ohnishi et al. (2018) propose a model that evaluates energy recovery efficiency by considering the costs and benefits of a waste-to-energy system. They analyze several scenarios characterized by different waste quantity/quality, waste separation system, and waste-to-energy production technologies. Other papers are focused on recovering heat produced as waste by incinerators (Dou et al., 2018a) or companies (Dou et al., 2018b; Kanematsu et al., 2017; Kim et al., 2018). In particular, Dou et al. (2018a) develop an integrated model to assess the economic and environmental feasibility of developing a heat exchange network between incineration facilities and industries in city scale. Dou et al. (2018b) combine the system development of district heating system and land use scenarios into a symbiotic design based on inventory survey and geographic database and conduct a cost-benefit analysis to scientifically and quantitatively evaluate the effects brought from land-use policies. Kanematsu et al. (2017) propose a model and simulations of a plant using wastes produced by sugar plant to produce heat for the district heating system. Finally, Kim et al. (2018) conduct an analysis of different scenarios of heat recovery of heat produced in Ulsan eco-industrial park, assessing the economic and environmental benefits of each scenario.

3.3 Symbiotic synergies implemented

The IS synergies described by the analyzed papers are displayed in Table 3. Each synergy is categorized as material-based, water-based, or energy-based.

3.4 Barriers and enablers

Urban symbiosis projects are characterized by a high level of complexity because involving multiple stakeholders (e.g., citizenships, companies producing and using wastes, government, companies collecting wastes) that have usually different interests (Sun et al., 2017). In this regard, the literature shows that strong cooperation among all the above-mentioned stakeholders is a *conditio sine qua non* for the effective implementation of IS projects. In this sense, a widespread recognition among all stakeholders that the industrial environmental pollution needs to be reversed acts as a facilitator for the development of IS projects (Van Berkel et al., 2009b). Alternatively, where this awareness is low, the adoption of the IS approach is more difficult (Dong et al., 2013a). Hence, in order to improve the stakeholders' awareness on IS, activities related to the IS concept such as TV promotions, newsletters, achievement exhibitions, and workshops might be promoted (Dong et al., 2013a).

From the technical perspective, some important issues affecting the adoption of IS can be highlighted. First, a minimum amount of waste is required to ensure the technical and economic feasibility of IS (Li et al., 2015; Ohnishi et al., 2017). If the amount of the available wastes is lower than the minimum amount required, companies have no willingness to implement IS.

Table 3. Synergies of IS proposed, designed, or developed for urban areas.

Waste	***Producer***	***Use/Input replaced***	***User(s)***	***Category***	***Cities***
Mixed urban wastes	Households	Coal	Cement production	Energy-based	Kawasaki
Plastic wastes	Households	Coal	Cement production	Energy-based	Kawasaki
			Iron and steel production	Energy-based	Liuzhou, Jinan, Guiyang
Waste tires	Households	Coal	Cement production	Energy-based	Liuzhou
			Iron and steel production	Energy-based	Guiyang
Fly ash	Households		Cement production	Material-based	Kawasaki
Wastewater sludge	Wastewater treatment plant	Limestone	Cement production	Material-based	Kawasaki
Mixed plastic	Households	Used to produce synthesis gas	Ammonia production process	Energy-based	Kawasaki
		Plywood	Concrete production	Material-based	
Treated water	Wastewater treatment process	Industrial water	Paper production	Water-based	Kawasaki
			Cement production	Water-based	
			Iron and steel production	Water-based	Jinan
Surplus soil	Urban construction sites	Clay	Cement production	Material-based	Kawasaki
Food waste	Households	Incinerated for energy production	Incinerator	Energy-based	Liuzhou
Waste heat	Companies	Heat	Households	Energy-based	Shinchi Town, Ulsan
Organic wastes	Companies	Heat	Households	Energy-based	Tanegashima

In addition to the quantity, the stability of waste flows is a fundamental requisite. In this regard, one of the main barriers in China is the difficulty to provide a stable urban waste supply to companies, due to the lack of a stable waste recycling system (L. Dong et al., 2014) and information obstacles (Dong et al., 2016). In fact, both the amount and the characteristics of urban wastes (e.g., the content of plastic wastes) supplied to companies may fluctuate over time (Dong et al., 2013b). Such a fluctuation might lead to inefficiencies from the operational perspective, so that designing and managing IS relationships becomes a hard task (Cao et al., 2017). Hence, establishing an urban waste recycling system is fundamental for the application of IS, so that adequate wastes can be collected and delivered to the right users (Dong et al., 2013a). Of course, city governments should ensure a detailed separation program for urban wastes collection and all urban waste producers should be encouraged to take part (Hashimoto et al., 2010; Ohnishi et al., 2017). For example, the waste collection and separation system can be improved through social education system, which may lead to a higher public awareness on implementing source separation through voluntary actions (H. Dong et al., 2014). Concerning the information obstacles, companies might face difficulties in exploiting urban wastes because not aware of what kind of wastes are produced in a specific urban area, the amount produced, and the production rate (Dong et al., 2016). To overcome this obstacle, governments can create online information platforms collecting data concerning potential supply and demand for wastes produced at the urban level and sharing them with the local companies (Chen et al., 2012; Fraccascia and Yazan, 2018). Finally, some wastes might require a treatment process before being used as inputs by companies. For example, the use of plastic waste as an alternative fuel requires that the waste is sorted for removing impurities (Hashimoto et al., 2010). Waste treatment technology is a fundamental enabler for the application of IS since it determines whether urban wastes can be reused by local companies (H. Dong et al., 2014; Dong et al., 2016; Li et al., 2015). If appropriate technologies are not available or not economically affordable, the IS becomes no more feasible.

From the economic perspective, the economic feasibility of IS projects is strongly affected by: (1) the price of waste disposal and input purchasing; and (2) the additional investments required to implement IS synergies. In particular, the higher the price of waste disposal and input purchasing, the more economically feasible the IS project will be, *ceteris paribus*. However, some studies put in evidence that in China these prices are low and, for this reason, companies might be not motivated enough to replace inputs with wastes (Cao et al., 2017; Li et al., 2015). Additional investments can be required to implement IS synergies, for instance to build infrastructure and facilities (Dong et al., 2017, 2013a; Geng et al., 2010). This makes the IS costly in the short time, as the required investments are usually high (Dong et al., 2017). Furthermore, investing in symbiotic projects might be considered as risky by companies, mainly because of the above-mentioned uncertainty in waste flows in the long period, which affects revenues (Van Berkel et al., 2009b). Governments can play a fundamental role in the implementation of IS through policy actions and economic incentives. In fact, governments can adopt a waste management legislation which motivates companies to participate in IS projects, for example by introducing mandatory recycling targets for urban wastes (Dong et al., 2013b; Van Berkel et al., 2009a), taxes on environmental emissions (Dong et al., 2016), and applying ecological compensation policies impacting on the market prices of inputs (Sun et al., 2017). Furthermore, governments can provide companies with financial subsidies aimed at establishing IS projects (Dong et al., 2013b), subsidizing the physical infrastructures required (e.g., pipelines for waste energy exchanges) (L. Dong et al., 2014), and providing research funds for R&D activities aimed at improving waste recycling technologies (Dong et al., 2016).

4. Conclusions

This is the first paper providing a comprehensive view of how IS within urban areas has been addressed so far by the literature. 26 papers published between 2009 and 2018 have been analyzed, aimed at highlighting the specific research goals addressed, the IS synergies currently implemented within urban areas, and barriers and enablers to the implementation of IS within urban areas. Here, there are some suggestions for future research:

- According to results, different IS synergies can be implemented in different cities. Hence, identifying in a systematic way the urban features able to affect the implementation of IS synergies can be a matter for future research;
- Waste collection processes could be optimized in order to take into account operational constraints stemming from IS synergies (e.g., the demand for wastes by companies) in addition to economic and environmental constraints already considered by the literature;
- IS synergies within urban area could be integrated with traditional IS synergies among companies;
- The business models behind this approach need to be analyzed. Furthermore, specific contractual clauses should be developed in order to ensure that the economic benefits created will be fairly shared between companies and citizens.

References

Albino V., Fraccascia L., Savino T., (2015), Industrial Symbiosis for a Sustainable City: Technical, Economical and Organizational Issues, *Procedia Engineering*, **118**, 950–957.

Cao X., Wen Z., Tian H., De Clercq D., Qu L., (2017), Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem: A Case Study of an Industrial City in China, *Journal of Industrial Ecology*, **22**, 881–893.

Chen X., Fujita T., Ohnishi S., Fujii M., Geng Y., (2012), The Impact of Scale, Recycling Boundary, and Type of Waste on Symbiosis and Recycling, *Journal of Industrial Ecology*, **16**, 129–141.

Chertow M.R., (2000), Industrial Symbiosis: Literature and Taxonomy, *Annual Review of Energy and the Environment*, **25**,

313–337.
Dong H., Ohnishi S., Fujita T., Geng Y., Fujii M., Dong L., (2014), Achieving carbon emission reduction through industrial and urban symbiosis: A case of Kawasaki, *Energy*, **64**, 277–286.
Dong L., Dai M., Ren J., Fujii M., Wang Y., Ohnishi S., (2016), Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China, *Journal of Cleaner Production*, **114**, 387–400.
Dong L., Fujita T., Zhang H., Dai M., Fujii M., Ohnishi S., Geng Y., Liu Z., (2013a), Promoting low-carbon city through industrial symbiosis: A case in China by applying HPIMO model, *Energy Policy*, **61**, 864–873.
Dong L., Gu F., Fujita T., Hayashi Y., Gao J., (2014), Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects in China, *Energy Policy*, **65**, 388–397.
Dong L., Liang H., Zhang L., Liu Z., Gao Z., Hu M., (2017), Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China, *Ecological Modelling,* **361**, 164–176.
Dong L., Zhang H., Fujita T., Ohnishi S., Li H., Fujii M., Dong H., (2013b), Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan, *Journal of Cleaner Production,* **59**, 226–238.
Dou Y., Ohnishi S., Fujii M., Togawa T., Fujita T., Tanikawa H., Dong L., (2018a), Feasibility of developing heat exchange network between incineration facilities and industries in cities: Case of Tokyo Metropolitan Area, *Journal of Cleaner Production*, **170**, 548–558.
Dou Y., Togawa T., Dong L., Fujii M., Ohnishi S., Tanikawa H., Fujita T., (2018b), Innovative planning and evaluation system for district heating using waste heat considering spatial configuration: A case in Fukushima, Japan, *Resources Conservation and Recycling*, **128**, 406–416.
Fang K., Dong L., Ren J., Zhang Q., Han L., Fu H., (2017), Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China, *Ecological Modelling*, **365**, 30–44. doi:10.1016/j.ecolmodel.2017.09.024
Fraccascia L., Yazan D.M., (2018), The role of online information-sharing platforms on the performance of industrial symbiosis networks, *Resources Conservation and Recycling*, **136**, 473–485.
Fujii M., Dong L., Lu C., Behera S.K., Park H.-S., Chiu A.S.F., (2016), Possibility of developing low-carbon industries through urban symbiosis in Asian cities, *Journal of Cleaner Production*, **114**, 376–386.
Geng Y., Tsuyoshi F., Chen X., (2010), Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki, *Journal of Cleaner Production*, **18**, 993–1000.
Gibbs D., Deutz P., (2005), Implementing industrial ecology? Planning for eco-industrial parks in the USA, *Geoforum*, **36**, 452–464.
Grimm N.B., Faeth S.H., Golubiewski N.E., Redman C.L., Wu J., Bai X., Briggs J.M., (2008). Global change and the ecology of cities, *Science*, **319**, 756–60.
Hashimoto S., Fujita T., Geng Y., Nagasawa E., (2010), Realizing CO2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki. *Resources Conservation and Recycling*, **54**, 704–710.
Huang W., Gao Q.-X., Cao G., Ma Z.-Y., Zhang W.-D., Chao Q.-C., (2016), Effect of urban symbiosis development in China on GHG emissions reduction. *Advances in Climate Change Research*, **7**, 247–252.
Jacobsen N.B., (2006), Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects, *Journal of Industrial Ecology*, **10**, 239–255.
Kanematsu Y., Oosawa K., Okubo T., Kikuchi Y., (2017), A design of rural energy system by industrial symbiosis considering availability of regional resources, *Computer Aided Chemical Engineering*, **40**, 1987–1992.
Kim H.-W., Dong L., Choi A.E.S., Fujii M., Fujita T., Park H.-S., (2018), Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea, *Resources Conservation and Recycling*, **135**, 225–234.
Lenhart J., van Vliet B., Mol A.P.J., (2015), New roles for local authorities in a time of climate change: the Rotterdam Energy Approach and Planning as a case of urban symbiosis, *Journal of Cleaner Production*, **107**, 593–601.
Li H., Dong L., Ren J., (2015), Industrial symbiosis as a countermeasure for resource dependent city: a case study of Guiyang, China, *Journal of Cleaner Production*, **107**, 252–266.
Li H., Dong L., Xie Y.T., Fang M., (2017), Low-carbon benefits of industrial symbiosis from a scope-3 perspective: a case study in China, *Applied Ecology and Environmental Research*, **15**, 135–153.
Ohnishi S., Dong H., Geng Y., Fujii M., Fujita T., (2017), A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan, *Ecological Indicators*, **73**, 315–324.
Ohnishi S., Fujii M., Ohata M., Rokuta I., Fujita T., (2018), Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city, *Resources Conservation and Recycling*, **128**, 394–405.
Park H.-S., Rene E.R., Choi S.-M., Chiu A.S.F., (2008), Strategies for sustainable development of industrial park in Ulsan, South Korea—From spontaneous evolution to systematic expansion of industrial symbiosis, *Journal of Environmental Management*, **87**, 1–13.
Sacirovic S., Ketin S., Vignjevic N., (2018), Eco-industrial zones in the context of sustainability development of urban areas, *Environmental Science Pollution Research*, 1–11.
Shell International BV (2014), *New Lenses on Future Cities*, online at http://s05.static-shell.com/content/dam/shell-new/local/country/sgp/downloads/pdf/new-lenses-on-future-cities.pdf.
Sun L., Li H., Dong L., Fang K., Ren J., Geng Y., Fujii M., Zhang W., Zhang N., Liu Z., (2017), Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China, *Resources Conservation and Recycling*, **119**, 78–88.
The World Bank, (2012), *What a waste. A global review on solid waste management*, online at: https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf
Van Berkel R., Fujita T., Hashimoto S., Fujii M., (2009), Quantitative Assessment of Urban and Industrial Symbiosis in Kawasaki, Japan, *Environmental Science & Technology*, **43**, 1271–1281.

Van Berkel R., Fujita T., Hashimoto S., Geng Y., (2009b), Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006, *Journal of Environmental Management*, **90**, 1544–1556.

Yang X., Wang Y., Sun M., Wang R., Zheng P., (2018), Exploring the environmental pressures in urban sectors: An energy-water-carbon nexus perspective, *Applied Energy*, **228**, 2298–2307.