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Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China

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ABSTRACT

Industry is double-edge sword to urban sustainability: on the one hand, it provides employment and GDP economic, one the other hand, brings pollutions to cities. The concept of urban industrial symbiosis offers a smart solution for city to coordinate the relationship among industries and between industry and city. While internationally, this idea has been promoted more than two decades, in China, which is ideal laboratory to test such practices, related research is rather few, especially quantitative studies. With this circumstance, this study conducts a case study to test the urban industrial symbiosis promotion in one typical industrial city named Liuzhou, in southern China, of which heavy industries play an important role. A hybrid evaluation model integrating process based life cycle assessment (LCA) and input-output (IO) model is established to assess the environmental benefits in the whole supply chain. Based on local conditions, innovative urban industrial symbiosis is designed and analyzed. Five new waste/energy synergies named waste plastics recycling, scrap tire recycling, coal flying ash recycling, biomass utilization and carbon capture by slag carbonization are selected for scenarios analysis. We particular focus on the carbon mitigations. Compared with business as usual scenario, planned symbiosis enables to reduce CO_2 emissions by 29.66, 557.42 and 520.13 kt-CO_2/year in power purchase, material consumption and waste disposal stage. Results highlight that urban industrial symbiosis is not only able to green the industries, but also utilize industry contribute to urban development. Finally, policy implications and countermeasures to address the barriers of promoting the urban industrial symbiosis are discussed. Our research would be critical for future sustainable urban planning and shed a light on regional eco-industrial development in China.

1. Introduction

With population, resources, infrastructures and capital intensive, cities have become the main drivers for human beings' resource consumption and waste generation (Kennedy et al., 2010; Leimer, 2015). As a result, in response to the fight to climate change, there is no doubt that cities are critical and become the hot spot for adopting various mitigation actions and policies (Bruestle, 1993; Hamin and Gurran, 2009; Xu et al., 2012), and cities were reported to account for over 70% of global Greenhouse gas (GHG) emissions (Liu et al., 2012). Therefore, low-carbon promotion in urban level deserves intensive attention. In addition, as the engine for economic development, industries plays critical role for creating economic values and human prosperity and meanwhile generating environmental impacts, and usually intertwines with the urbanization procedure (e.g. numerous industrial plants locate in urban regions) (Fujii et al., 2016). Therefore, properly greening the industries and coordinating their relationship with cities is critical topic for urban sustainability.

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Regional eco-industrial development (EID), which emphasizes the harmonious development of regional economies, industries and environmental protection, offers an innovative pathway to address the above challenges for urban and industrial development (Dong et al., 2016). Via integrated waste management, resource reuse and recycling, as well as the symbiotic network construction between industries, EID provides a novel approach for linking the industry and cities to meet with both environmental challenges and resource depletion challenges.

As one of the core implications of EID, the concept of urban industrial symbiosis (simplified as "UIS") provides an innovative solution. Illustrated as Fig. 1, industrial symbiosis (IS) is defined as a relationship in which various industries (and or companies) exchange materials, energy and/or by-products in a mutually beneficial way (Chertow, 1998, 2000, 2007; Desrochers, 2004; Ehrenfeld and Gertler, 1997; Mirata and Emtairah, 2005; Pearce, 2008; Van Berkel et al., 2009; Zhu et al., 2007). As an expansion of IS, urban symbiosis pursuits the opportunity arising from the geographic proximity of urban and industrial areas (Chen et al., 2011; Geng et al., 2010; Van Berkel et al., 2009), innovatively utilizes the societal waste into industries and reducing the related resource exploration and environmental impacts. By optimizing the process integration, resource, energy and waste exchange among industries and cities, as well as sharing the infrastructures, UIS offers a novel pathway to harmonize the industries and urban areas.

With rapid and intertwined urbanization and industrialization, China offers an idea laboratory to practice the EID. China is highlighted to be at a stage of surging economic growth, rapid urbanization and industrialization, as well as increasing environmental concerns. Particularly, China is featured with intertwined industrialization and urbanization. For example, there are over twenty provincial capital cities in China own large scale iron/steel and cement companies (Zhang et al., 2013a; Zhang et al., 2013b). China is famous for its "world factory", especially process industries. Large scale industries bring intensive resource consumption and emissions (Dong et al., 2014). It also has more numerous and larger cities than ever before. In 2010, the urban population in China has increased to more than 660 million, with an urbanization rate of 49.68% (Fig. 2). These numbers are expected to up to 850 million and 60.00% according to Chinese government's estimation.[1] It indicates an emerging concern of sustainable urban development in China (NBS, 2011; UN, 2012). Such a condition requires smart way to build a harmonious relationship between urban area and industry, focusing on two-level commissions: (1) greening the industry itself; (2) constructing a smart and efficient way to coordinate the industry and the urban area and transform them into a more harmonious format (Dong et al., 2014). And EID will enable to provide a pathway to address the above challenges. However, to date, there are only limited studied with focuses on this topic.

According to above highlights, practice of EID and urban industrial symbiosis is beneficial, and a verification on its environmental benefits will offer value added information to decision makers. Globally, urban industrial symbiosis has been promoted in developed countries for about two decades and considerable environmental benefits are demonstrated in pioneer projects (Behera et al., 2012; Hashimoto et al., 2010; Jacobsen, 2006; Mirata, 2004; Van Berkel et al., 2009; Zhu et al., 2007), e.g. Kanlundburg, Denmark, and eco-town project in Japan. As to China, this strategy is not so well recognized by local policy makers and planers (Dong et al., 2013c). In research field, to date, the quantitative analysis on the environmental performance of IS is rather few, largely due to data availability and regional models. Material flow analysis (MFA) and life cycle assessment (LCA) is mature tool for quantitatively evaluation (Berkel et al., 2009; Hashimoto et al., 2010; Jacobsen, 2006; Mattila et al., 2012; Mattila et al., 2010; Sokka et al., 2011), but few applied in Chinese cases, mainly due to the data availability. Hybrid approach, like the integration of process based LCA with input-output analysis (IOA), and MFA with IOA, improves the data scarcity condition for urban industrial symbiosis research (in this case, IO database enables to provide lacked up-stream and down-stream data), hence offers effective tool to evaluate the life cycle benefits of urban industrial symbiosis, but few applied in the context of China (Dong et al., 2016). As a result, the lack of reported information on real IS project harm to the project generalization and practical policy implications.

Based on this circumstance, this study aims to investigate the role of EID on the ever-improvement of regional metabolism. Based on the local practical project and first hand data via survey, design on urban industrial symbiosis scenarios in one typical industrial city named Liuzhou, southern China is conducted. We further investigate the life cycle environmental benefits applying with hybrid approach with integrating process analysis and IOA. This paper expects to contribute to the literatures with improved modeling approach and quantitative case studies supporting local urban industrial symbiosis initiatives. Our findings would be critical for future China's sustainable urban planning and regional development policy making.

The remainder of this paper is organized as: after this introduction section, Section 2 presents the methods and data; Section 3 overviews the case investigated in this research; Section 4 presents the analytical results and discussions; and finally, Section 5 draws the conclusions and policy implications.

2. Methods and data

2.1. Framework of evaluation model

In order to assess the life cycle environmental benefits of urban industrial symbiosis, a hybrid model is established with the integration of process based LCA (or MFA) and IOA. Comparison to the projection of urban industrial symbiosis scenarios, traditional linear process (waste disposal and landfill) is treated as business as usual scenario (BAU). Fig. 3 illustrates the framework of model integration.

The core part is the integration of process analysis and IO model. The former trace the process flows and emissions inventories specifically related to the symbiotic network, e.g. waste exchanges among companies and industries and related emissions. IO model could provide up-stream and down-stream flows information. In this way, we enable to analyze with material flows and emission inventories to see how the industrial park level metabolism can be improved. We can further use IOA to assess the change in embodied impacts in the product (or waste) flows to and out of the industrial park. The life cycle consumption and emission with and without urban industrial symbiosis implication hence could be evaluated under various scenarios (e.g. different symbiosis scenarios). By evaluating such impacts, several scenarios will provide to the local stakeholders for better planning on the industrial parks and cities. It is noted that we mainly focus on the carbon emissions in this study.

2.2. An improved hybrid IO model

To support the evaluation with IOA, an improved urban level hybrid physical input and monetary output model (HPIMO), which is established in our previous study (Dong et al., 2013b), is applied to assess how various symbiosis scenarios could contribute to energy

[1] http://www.china.org.cn/china/2012-05/04/content_25299433.htm.