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Regional and temporal simulation of a smart recycling system for municipal organic solid wastes

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ABSTRACT

A cost-effective and robust waste treatment and recycling system is a requisite of a sustainable society. In our previous study, we proposed a “smart recycling system” that utilizes existing industrial facilities with higher energy efficiency so that a cost-effective and robust recycling system for treating municipal wastes can be established. In this study, we further develop the concept of smart recycling and propose a framework for facilitating the implementation of such a system. By making use of existing facilities and adopting both closed-loop and semi-closed-loop recycling processes, this system allows flexible adaptations on the changes of external factors. A spatially optimal scale is necessary to meet the requirements for such a smart recycling system. Thus, we develop an integrated model that combines both geographical information system based collection model and a process model for a smart recycling center. In order to test its applicability, we employ a case study approach to simulate the implementation of smart recycling in the three satellite cities of Tokyo Metropolitan Area and evaluate its effects under three different scenarios. Our simulation results show that smart recycling cannot only reduce carbon dioxide emission but also lower the overall costs. Also, by comparing with conventional waste incineration, we find that the unit cost of smart recycling is relatively stable to changes of the waste amounts due to its lower fixed costs for facilities.

1. Introduction

With the increasing concerns on climate change and resource depletion, promotion of resource-saving through 3R (reduction, reuse and recycling) has become critical. Recycling and incineration (energy recovery) of municipal solid wastes (MSW) are useful co-benefit measures that can reduce the total amount of landfilled wastes, exhaustible resources and greenhouse gases (GHGs) emissions. Many studies have been undertaken to design an efficient waste treatment and recycling system that can address both resource consumption and environmental load (Astrup et al., 2009; Koroneos and Nanaki, 2012; Sekine et al., 2009), as well as cost (Bohm et al., 2010; Chang et al., 2012; Reich, 2005). They also proposed alternative or optimal solutions so that innovative methods can be applied under different conditions. Meanwhile, when estimating the cost-effectiveness of waste treatment and recycling systems, we need to consider the potential impacts of different future development patterns. For example, potential changes on future populations and lifestyles may lead to different amounts and components of waste generation, thus, resulting in different demands on recyclable products. Under such a circumstance, it is critical to develop a robust waste treatment and recycle system so that such changes can be coped with more appropriately.

In order to fill such a gap, we recently proposed a new concept of “smart recycling” to evaluate the effects of innovative waste management on carbon dioxide (CO_2) emissions and cost reductions (Fujii et al., 2012). This concept was based on “urban symbiosis” (Geng et al., 2010; van Berkel et al., 2009), which spatially expands the concept of “industrial symbiosis” (Chertow, 2000). Based on the

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Abbreviations: GHG, greenhouse gas; MSW, municipal solid waste; PET, polyethylene terephthalate; SMF, solid raw material and fuel; SRC, smart recycling center.

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synergistic opportunity arising from the geographic proximity through the transfer of physical resources (waste materials) for environmental and economic benefits, urban symbiosis can be defined as "the use of byproducts (wastes) from cities (or urban areas) as alternative raw materials or energy sources for industrial operations (Geng et al., 2010). A smart recycling system refers to actual implementation of urban symbiosis since it utilizes MSW from neighboring cities as raw materials or potential fuels for existing industrial plants and power stations. Such a use of wastes as industrial inputs can greatly reduce CO_2 emissions as a result of fossil fuel resource substitution (Sekine et al., 2009). In addition, the amount of organic solid wastes used in an industry as fuels or chemical feedstock is generally smaller than the amount of original fossil resources used. This makes the recycling system more robust because it is not influenced by the changes both in the amount of waste generated and the demand for recycled wastes. Furthermore, if a considerable amount of wastes can be recycled, the number of incinerators for conventional waste treatment can be reduced. Thus, by utilizing existing and more energy-efficient industrial facilities, a smart recycling system is both cost-effective and robust, despite changes in waste generation and demand for recycled products. Such a system is similar to a smart grid system because both of them attempt to use low-carbon but fluctuating resources to the possible extent by utilizing existing facilities.

In order to improve the cost-effectiveness of a waste treatment and recycling system, the collection of MSW from a spatially dispersed area, which accounts for a large percentage of the overall cost, should not be ignored. In this regard, the geographical characteristics of the study area should be carefully considered. Optimization of waste collection routes was studied previously (McLeod and Cherrett, 2008; Zsigraiova et al., 2013). Several recent studies conducted a comprehensive evaluation on waste management from collection to recycling and treatment in an actual or a virtual region (Chen et al., 2011; Merrild et al., 2012). In addition, the effect of geographic proximity between recycling facilities and waste generation sites (Ohnishi et al., 2012) and modeling of optimal facility location (Erkuta et al., 2008) was investigated.

Based upon these studies, the purpose of this paper is to demonstrate an innovative method to plan a smart waste treatment and recycling system, which is not only cost-effective but also robust for the changes of external factors such as population and consumption behavior. In order to test its applicability, a case study approach was employed, which can reflect more practical and geographical characteristics. The case study area is the three satellite cities within the great Tokyo region, Japan, where the treatment of MSW has been highly dependent on incinerators of the local municipalities. In our previous study (Fujii et al., 2012), an effect simulation on smart recycling was done as a function of population density and the capacity of the recycling facility (a "smart recycling center": SRC), in which smart recycling can result in a reduction of approximately 100 kg of CO_2 emissions per capita per year without increasing costs if the capacity of the SRC was set appropriately. However, this simulation was simply based on the assumption that wastes generation is static after the implementation of the new recycling program. Also, we simply assumed that the number of incinerators would decrease in proportion to the decreased amount of incinerated wastes. In this paper, we extend the concepts from previous studies and provide more valuable policy insights. We first describe the qualitative requirements for a robust waste treatment and recycling system and then conduct a more practical simulation by applying such a system in Japanese cities. The waste collection process was evaluated more precisely by using a geographic information system (GIS). Other factors, such as location, treatment capacity and operational life, were also considered. Fixed costs for construction and maintenance, and variable costs, such as labor, electricity, industrial water and chemical agents, were separately estimated in order to undertake a dynamic simulation according to changes of the waste amounts. In addition to the SRC, which produces both recycled plastic resin and solid raw material and fuel (SMF) for material industries and power plants (SRC-A), we also tested a simplified SRC, which produces only SMF and is designed for less populated areas (SRC-B).

2. Qualitative requirements for a robust recycling system

In this section, we describe the qualitative requirements for a robust waste treatment and recycling system so that the stakeholders, such as policy makers and urban planners, can plan their waste management by considering their own situations.

2.1. Factors that influence the operation of a robust recycling system

A preferable waste treatment and recycling system should save a large amount of virgin resources and significantly reduce environmental emissions, as well as reduce the total costs. In addition, it should not be influenced by changes in the waste amounts and compositions or the demand for recycled products. Fig. 1 shows various factors that directly or indirectly influence a waste treatment and recycling system. From the waste supply point of view, future waste generation amounts will change in proportion to the local population (McBean and Fortin, 1993); therefore, the future population should be estimated. Also, per capita waste generation amounts and the waste composition may change due to income levels, consumption patterns, promotion of reduction (e.g. reduction of packaging weight) and reuse and other factors (Memon, 2010). Thus changes in population, consumption behaviors, weight reduction, product reuse and economic conditions,

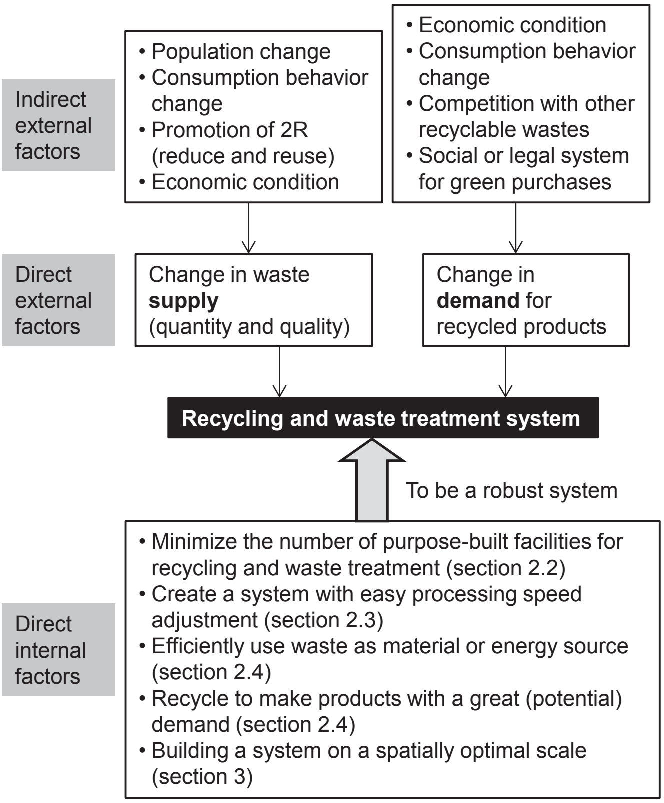

Fig. 1. Factors involved in a robust waste treatment and recycling system.