

# Spatial Analysis and Evaluation System for the Planning of Regional Recycling Network: Empirical and Case Studies in Japan

地域循環ネットワークの計画のための空間分析・  
評価システムに関する研究  
—日本における実証及び事例研究

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## Summary

In recent years, urban development caused multiple, comprehensive environmental problems simultaneously, such as resource depletion, shortage of waste disposal space, and global warming, which in turn hindered further development of cities. These pressures require a transition in the urban system from the conventional “mass production-consumption- disposal” style towards high resource efficiencies and less disposal of wastes so as to reduce the environmental burden of urban activities. Actions need to be taken in all processes of material flows through urban systems, including production, logistics, consumption, and treatment of wastes. Among numerous approaches, recycling through industrial symbiosis, namely using MSW as raw materials in industrial production, is an effective way to mitigate the pressures. Research efforts have been made on the operational level, such as increasing recycling rates and developing and assessing new recycling technologies.

Technologies are not independent from the social system. A particular aspect that has not been sufficiently addressed is the collection and pretreatment system. In Japan, municipalities are assuming the responsibility for collecting and pre-treating recyclable municipal solid waste. Most municipal recycling centers are in small scales (i.e. small treatment capacity) and of high costs. Enlarging the scale of recycling centers leads to the establishment of a regional recycling network, which bridges spatially diffuse sources of wastes and agglomerated clusters of industrial facilities. Determining appropriate boundaries of recycling for different types of wastes becomes important and necessary in planning for regional recycling. However, both empirical and modeling studies are lacking in the literature.

This doctoral dissertation aims to quantitatively explore the mechanism and key factors that determine the proper boundary of regional recycling through industrial symbiosis by both empirical studies and a case study on waste plastics recycling in the National Capital Region in Japan. It has three tightly linked objectives. Towards this goal, this dissertation has the following three objectives: (1) to identify features of existing recycling facilities in different scales and types in Japan; (2) to develop models for optimizing the number, capacity, and

locations of regional recycling centers (RRCs) and assessing the environmental benefits and eco-efficiency of regional recycling through industrial symbiosis; and (3) to design regional recycling networks with multiple layers for different types of wastes according to their properties and promotion policies.

This paper is organized as follows:

Chapter 1 introduces the background of this dissertation. It notes that given the limitation in the carrying capacity of our “spaceship”, earth, in terms of resource supply and waste disposal, in order to maintain or even upgrade the urban living environment, the efficiencies of utilizing resources must be increased. For closing the material-loop in urban systems, a possible approach is to utilize waste as resource directly in industrial facilities. To materialize this concept in practice, both technologies (hardware) and a supporting social system (software) are required. Three problems need to be addressed for further improving recycling. First, it is necessary to address not only the amount of recycling, but also the efficiency of utilizing wastes. Second, the scale of recycling centers in municipalities for pre-treatment (e.g. separation, compressing, or bailing) is usually small so that the average cost of pre-treatment is relatively high. Third, planning for regional recycling through IS, including the design of regional recycling networks and promoting policies, requires sound supports of scientific studies. Therefore, it is important to study the mechanisms and factors that determine appropriate recycling boundaries of different types of wastes. The research objectives and dissertation structure are also introduced.

Chapter 2 reviews relevant literature to identify research gaps and solidify the theoretical foundation of this study. Because topics concerning recycling have long been regarded as a part of waste management in both practice and research, Chapter 2 begins with a brief review on how waste management has been evolved in the recent history. It then reviews models often employed in waste planning and management to identify the gaps in research for improving the efficiency of recycling, establishing regional recycling networks, and issuing comprehensive policies for promoting regional recycling through industrial symbiosis. The review finds that most widely adopted models focus exclusively on managing waste, which is a limited scope not looking at the potential of industries. They also focused mainly at the municipal level. Regional recycling is not a main topic in research and practices. To resolve these issues requires knowledge beyond the scope of conventional waste management and planning. As propositions, studies related to industrial symbiosis, regional recycling, and socio-technical transition for policy-making are reviewed.

Chapter 3 introduces empirical studies on recycling activities in Japan. With its achievements in recycling and industrial symbiosis and high accessibilities to relevant data, Japan offers a precious opportunity for empirical study on recycling. Chapter 3 first examines recycling boundary and facility scale at the project level, analyzing first hand survey data acquired from recycling facilities to identify relationships between scale, recycling boundary,

waste type, and performances of recycling facilities. Next, it zooms out to the national scale, examining the spatial distribution and clustering of waste generation, incineration, separate collection, and recycling processing. The empirical studies find that large recyclers appear to be more stable in operation; agglomeration of recycling facilities in eco-towns does not appear to have advantages over dispersed eco-towns; recycling boundary differs for different types of waste – transportation cost is likely to affect the result; and for processing waste plastics, clusters are present.

Chapters 4 and 5 present the case study on recycling of waste plastics in the National Capital Region of Japan. Chapter 4 introduces general methodologies in terms of a planning model, scenario design, modification of an optimization model to count economies of scale when determining number, capacity, and location of RRCs, and an LCA model for assessing environmental benefits of regional recycling networks. Chapter 5 details out the background of the case study region, model parameters, results, and theoretical discussions. The modeling aims not only at finding optimal solutions for the case study, but also at generalizing the results to other types of wastes and other regions. To do so, scenarios are designed to test various factors to identify key factors by comparing the results from all scenarios. The modeling results reveal two key factors that determined the proper boundary of recycling spatially diffused waste, density of recyclable wastes, and the ratio of unit transportation costs to unit treatment costs. In a given region where all municipalities are serviced, considering cost as a function of the number of hosting cities, i.e. the recycling boundary, the optimal solution is determined when the sum of marginal cost of transportation (MCT) and the marginal costs of construction + operation (MCCO) equals to zero.

Discussions about generalization of findings and policies implications are elaborated in Chapter 6. By identifying the two determinants for different types of wastes, proper recycling boundaries for them can be estimated. Such a theoretical deduction is verified by the empirical findings in Chapter 3. The findings lead to a design of regional recycling networks with multiple layers for different types of wastes. To establish such a regional recycling network requires coordinated efforts of various stakeholders. Comprehensive policies are discussed based on a model of socio-technical transition management in two aspects. First, policies need to identify the extent to which pressures are oriented coherently in a particular direction and translate pressures into a form that prompts and enables responses by the regime, referred as pressure articulation. Second, policies should contribute to the adaptive capacity of a regime, the capacity and resources to respond to the pressures bearing it, referred to as Resource coordination.

Finally, Chapter 7 draws conclusions on the major findings, contributions to literature and practices, and future studies.