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Econometric analysis of the performance of recycling projects in Japanese Eco-Towns

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ABSTRACT

Although, in the theory of industrial ecology, a recycling industry is essential in order to establish a closed loop material system, in practice, the contribution of that industry is still limited, and more studies are needed to enlarge its role. The objective of this paper is to quantitatively analyze factors that influence the performance of recycling projects in Japanese Eco-Towns. We develop two multi-regression models using questionnaire survey data from recycling facilities and cross-sectional data from 23 Eco-Towns to analyze the amount of waste treated by and the operating rate of recycling facilities. Dependent variables are introduced through a review of the literature on industrial symbiosis and the situation of Japanese Eco-Towns, focusing on three necessary features: recycling boundaries, government policy intervention, and local collaboration and partnership. The results of two simple regression models of recycling facilities in Eco-Towns offer several fruitful insights that aid in understanding the performance of recycling projects. First, recycling facilities' geographical proximity to users of recycled products can contribute to high operating rates. Second, subsidies for constructing facilities do not improve recycling projects' operating rates. Third, collaboration, rather than competition, among recycling facilities can improve their operating rates.

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1. Introduction

A current major societal challenge is how to shift from mass-production and mass-disposal toward a more sustainable way of using limited natural resources. This topic is a focus of the industrial ecology (IE) research field, which aims to optimize energy, material, and capital throughout the lifecycle of materials (Graedel and Allenby, 2010). Concepts and models derived from the study of ecosystems, including the "industrial ecosystem" (Frosch and Gallopoulos, 1989; Korhonen, 2001, 2004), "industrial metabolism" (Ayres and Udo, 1994), and "urban metabolism" (Kennedy et al., 2007), have been introduced in order to learn from nature how materials can be sustainably metabolized. Theoretically, it is essential for industrial ecosystems to have at least one industrial decomposer (e.g., a recycling industry) and to create a symbiotic web among entities within the system (Liwarska-Bizukojc et al., 2009). In practice, although recycling, remanufacturing, and waste treatment firms have been active at the local level, their contributions to closing the material loop are still limited (Lyons, 2005). Therefore, there is great need for improvement in the recycling industry to establish more efficient recycling system, and, to that end, more studies are needed.

Recycling in general includes multiple processes, from waste separation and collection to processing and delivery of recycled resources back to production sites. One method of analyzing municipal solid waste (MSW) recycling activities is econometric analysis. It has been employed to explain factors influencing waste generation and recycling rates in municipalities. The theory of planned behavior is one of the theoretical frameworks used to analyze waste separation and minimization behaviors (Ajzen, 1991; Tonglet et al., 2004). Several empirical studies have focused on improving recycling rates (see the examples of Hage and Soderholm, 2008; Jahandideh et al., 2009). However, these studies discuss only the activities of the waste generation and separation processes and have not taken into account the entire recycling process flow and the performance of recycling industries.

Other approaches to scrutinizing the recycling activities of industry are case and empirical studies of industrial symbiosis (IS), the innovative frontier of recycling and waste/by-product and

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energy exchange among firms located near each other (Chertow, 2000). IS networks have created both environmental benefits and industrial competitiveness through projects such as eco-industrial parks (EIPs) in various countries such as Australia (van Beers et al., 2007), United States (Chertow et al., 2008), Brazil (Elabras Veiga and Magrini, 2009), China (Shi et al., 2010) and Japan (van Berkel et al., 2009a). Companies involved in IS are not usually recycling companies per se, but conventional independent enterprises without waste exchanges. Moreover, most IS studies are small-scale case studies of projects like EIPs. Quantitative analysis at the national level is not well documented in the literature.

This study focuses on analyzing the performance of the recycling process, in particular the operation of recycling facilities that treat MSW and industrial waste or by-products in Japanese Eco-Towns through the use of econometric models. Similar to using industrial wastes as production inputs, some of the MSW treated in Eco-Towns is directly utilized in industrial production. van Berkel et al. (2009a) introduced the term "urban symbiosis" (US) for such innovative recycling activities "based on the synergistic opportunity arising from the geographic proximity of urban waste sources and potential industrial users through the transfer of physical resources ('waste materials') for environmental and economic benefit" (p. 1545). Several papers discuss the performance and explore the potential of IS and US networks in Eco-Towns (Hashimoto et al., 2010; Geng et al., 2010; van Berkel et al., 2009a). And

The objective of this paper is to quantitatively analyze factors that influence the performance of recycling projects in Japanese Eco-Towns. We develop two multi-regression models using questionnaire survey data from recycling facilities and cross-sectional data from 23 Eco-Towns to analyze the amount of waste treated by and the operating rate of recycling facilities. Following this introduction, Section 2 of the paper provides a literature review for model formation and Section 3 introduces Japanese Eco-Towns' background and setting. Section 4 elaborates on the econometric models and data collection approaches. Section 5 presents the empirical results of the models and discussions. Section 6 draws conclusions from the results.

2. Literature review

This section provides a literature review on industrial and urban symbiosis. Through the review, we extracted three categories of factors that influence the success of industrial symbiosis, forming the conceptual framework for the regression model. We thus present the review by categorizing it into three sections concerning recycling boundary, government policy intervention, and local collaboration and partnership.

2.1. Recycling boundaries

Benefits from industrial symbiosis are gained from exchange of by-products and wastes and cascade use of water and energy among closely located enterprises, as is usually observed in EIPs. According to the definition introduced by Chertow (2000), "the keys to industrial symbiosis are collaboration and the synergistic possibilities offered by *geographic proximity*" (p. 313, *italic* emphasis added by the authors). Numerous case studies of EIPs in different countries around the globe have discussed the formation of industrial symbiosis within EIPs as well as their environmental, economic, and social benefits (Jacobsen, 2006; van Beers et al., 2007; Chertow et al., 2008; Elabras Veiga and Magrini, 2009; Shi et al., 2010; Hashimoto et al., 2010). The benefits of EIPs can also arise from united sharing, joint service provision, by-product exchanges, shared access to goods and services, a pool of experienced labor, financial and legal services, social cohesion, and personal contact (Deutz and Gibbs, 2008; Chertow et al., 2008). In other words, geographic proximity offers the opportunity for not only industrial symbiosis (i.e., waste and by-product exchanges) but also a range of other activities that can also benefit conventional industrial parks. These factors, however, are not sufficient to make geographic proximity a prerequisite for gaining benefits from waste and by-product exchanges.

An extension of industrial symbiosis is urban symbiosis, which involves recycling wastes generated by adjacent cities as industrial inputs (van Berkel et al., 2009b). Such practices in Japan benefit both waste management and industrial revitalization. There is still room for improvement if more recyclable wastes can be diverted from incineration or landfill to industries (van Berkel et al., 2009a; Geng et al., 2010). Historical evidence also supports the argument that regional level recycling has been a conventional practice for a long time (Desrochers, 2002). Sterr and Ott (2004) formed a conceptual model showing that, in terms of distance, the trends of "problem-solving competence" for a diversity of wastes and "personal affectedness" from ecologically unfavorable behavior intersect at a medium distance and argued that eco-industrial development on the regional scale is promising.

On closer inspection, recycling boundaries appear to vary for different type of wastes. Studies have shown that, in general, cascade uses of water and energy are usually take place among closely located entities; wastes with low market value that are costly to transport, such as organic and construction wastes, are recycled within relatively short distances, whereas wastes with high market values, such as metals and plastics can travel over a longer distance (Chen et al., 2012; Lyons, 2007; Shi et al., 2010).

With plausible evidence, it is still not certain if geographical proximity contribute more to stale operation of recycling facilities than diversity of supplies in the regional scale. Thus recycling boundaries thus seem to be a crucial factor influencing the performance of recycling projects.

2.2. Government policy intervention

Soon after the prototype of industrial symbiosis in Kalundborg was unveiled, numerous EIP plans making use of industrial and urban symbiosis have been initiated in different countries (e.g., Gibbs and Deutz, 2007; Geng et al., 2008; Fujita, 2006). With these initiatives, various types of governmental intervention were inevitable. For example, EIPs in China and Eco-Towns in Japan need to be approved and designated as entities by the national government (Geng et al., 2009; Fujita, 2006). From a management point of view, government policy intervention to improve waste exchange and recycling can include objective setting, regulation, economic incentives, and information sharing programs (Costa et al., 2010). Planning guidelines for EIPs also call for regulatory and economic tools to encourage waste exchange and waste reduction (Roberts, 2004; Côté and Eohen-Rosenthal, 1998). Appropriate governmental policy intervention has been found to contribute to industrial and urban symbiosis. For example, a combination of regulations on waste management, economic and regulatory tools penalizing lower hierarchy waste management options, and voluntary tools facilitating companies to seek synergistic opportunities helps shape a favorable context for industrial symbiosis (Costa et al., 2010).

Although most studies demonstrate the contributions made by policy intervention, several studies have also noted that some policy-led interchanges of wastes and energy have been hard to establish (Schlarb, 2001 cited in Gibbs, 2003). Moreover, heavy government involvement in the U.S. has hindered private companies who wished to locate their plants in planned EIPs, rendering

EIPs in the U.S. less successful than their European counterparts (Heeres et al., 2004).

Some reported that government policy intervention could be beneficial to create symbiotic networking whereas some pointed out that it hindered cooperation between companies. In addition to case studies and qualitative analysis, more empirical and quantitative analysis can help deepen our understanding of the role of policy intervention in industrial and urban symbiosis.

2.3. Local collaboration and partnership

Industrial and urban symbiosis must involve collaboration and partnership among firms and cities that generate or receive wastes and products. Such partnerships are importation for the formation and continuation of symbiosis. As Gibbs (2003) pointed out, "many of the key barriers to EIP formation revolve around issues of inter-firm networking, trust and the potential to cooperate" (p. 230). In the case of Kalundborg, it has been the long-term personal and professional relationships with one another that has made managers feel that this vulnerability has been mitigated (Dunn and Steinemann, 1998). In addition to companies, partnerships among other stakeholders, such as the government, educational institutions, community and environmental organizations, local representatives, and citizens also contribute to and seem to be indispensable in the success of industrial and urban symbiosis (Heeres et al., 2004; Gibbs and Deutz, 2007; GEC, 2006). However, once the exchanges are formed, industrial symbiosis creates a mutual dependency among companies, which makes industries sensitive to the changes in wastes and by-products of other industries.

Reviewing partnerships formed for waste minimization programs in the U.K., Phillips et al. (2006) summarized that a focus on local issues, projects with added value, and the presence of full time offers contribute to successful partnerships, while a lack of contractual relationships, insufficient long-term funding, confused communication, and a lack of well-designed information programs become major barriers. Several studies also analyzed or proposed ways by which these barriers can be overcome, such as establishing coordinating bodies, entrepreneur or employer associations, and information systems to lower transaction costs (Mirata, 2004; Heeres et al., 2004; Sterr and Ott, 2004).

It should be born in mind that the format of these partnerships may vary dramatically by country and case due to specific historical, cultural, and institutional regimes, existing linkages, and other local conditions. In the next section, we will introduce the quantifiable factors in Japanese Eco-Towns that fit the key aspects reviewed above, together with a brief history of the Eco-Town program.

3. State of Japanese Eco-Towns

In this section, we introduce the situation of Japanese Eco-Towns and quantify factors for the regression analysis that follows.

3.1. A brief introduction to the Eco-Town program

The Eco-Town program was initiated in 1997 to simultaneously achieve economic stimulation and resolve waste management issues (van Berkel et al., 2009b). The program ended in 2006. It was designed based on the zero emission concept, according to which "industries and companies keep the amount of waste generated by their activities to a minimum" (GEC, 2005, p. 5). Japan's Ministry of the Environment (MoE) and Ministry of Economy, Trade and Industry (METI) jointly approved 26 Eco-Towns after they reviewed and assessed the Eco-Town plans developed by local municipalities who, with intimate knowledge of local conditions, were able to devise plans from original and innovative points of view (Fujita, 2006). Once a planned area was approved as an Eco-Town, MoE and METI provided financial subsidies to both "software projects" (e.g., town planning, community recycling, and outreach activities) and "hardware projects" (e.g., innovative recycling projects) (van Berkel et al., 2009b; Fujita, 2006). As of the end of 2007, 170 recycling projects including 61 subsidized ones were operating in 26 Eco-Towns.

3.2. Recycling boundaries

Based on the survey data initiated by authors in collaboration with MoE, Chen et al. (2012) made a preparatory survey on Eco-Town project recycling boundaries, defined as the distances spanned by waste collection and product delivery. One finding was that while wastes that are costly to transport and have relatively low market values, such as MSW, debris, wood, and feces, are mostly collected within short distances, while metals, waste electrical and electronic equipment, plastics, paper, automobile shredder dust, and oil are mainly collected from long distances.

Project scale corresponds to transportation distance. Large recycling projects in Eco-Towns tend to be located closer to the end users of recycled products and thus have shorter distances to transport products for delivery. Moreover, the conditions of the cities or prefectures where the Eco-Town recycling facilities are located also vary significantly. Eco-Town facilities located in large cities such as Tokyo can enjoy geographical proximity to waste sources of since a large amount of MSW is treated within Tokyo. In contrast, the smallest city with an Eco-Town project, Naoshima Township in Kagawa, had a population of only about 3500 in 2010 where much less recyclable wastes could be collected locally. However, other drivers exist for Eco-Town projects. Naoshima has a large non-ferrous industry and is near an illegal dumping site that had been receiving wastes from adjacent areas (GEC, 2005). These show that local waste generation conditions and access to end users can also influence recycling projects' success.

Another important feature of Eco-Towns related to boundaries and geographical proximity is the distance between Eco-Town recycling projects, namely whether the Eco-Town is agglomerated or dispersed. For example, Sapporo's Eco-Town is agglomerated, and all of its recycling projects are located in one industrial park with an area of 23 ha. On the other hand, Hokkaido's Eco-Town is dispersed, and covers the whole of Hokkaido Prefecture. Although Chen et al. (2012) does not find significant differences in total waste treated and operating rates between agglomerated and dispersed Eco-Town facilities, it is worth testing their influence again in the regression model.

3.3. Government policy intervention

Studies on the Japanese Eco-Town program showed that specific recycling laws and subsidies from the national government played important roles in the establishment of recycling projects and the formation of urban symbiosis around Eco-Towns (GEC, 2006; van Berkel et al., 2009b).

The national government supports recycling projects in Eco-Towns in line with its policy of "establishing a sound material-cycle society". The "Basic Act for Establishing a Sound Material-Cycle Society" was enacted in 2001, adopting the philosophy of the Basic Environment Law and defining the hierarchy of preferred waste management methods from reduction, reuse, recycling, and energy recovery down to appropriate disposal. More direct regulations covering recycling projects are the Waste Management and Public Cleansing Law and the Law for the Promotion of Effective

Utilization of Resources, which stipulate the criteria for designating qualified recyclers to ensure the recycling efficiency. In addition, several recycling laws on specific wastes (e.g., containers and packaging, home appliances, construction materials, food, and end-of-life vehicles) were enacted from 2000 to 2003. Each law defines the responsibilities of stakeholders for recycling a particular type of waste. Recycling associations were also established as allowed by the recycling laws to coordinate, facilitate, and in some cases, manage funds for recycling. Facilities recognized by the national government and designated associations can gain support through recycling associations.

METI and/or MOE provided subsidies to selected projects in the range of 33–50% of the initial construction cost. In total, 61 projects with a total processing capacity of 1995 thousand tons per year received 165,787 million JPY in subsidies (van Berkel et al., 2009b). These subsidies contributed to the establishment of recycling facilities using leading technologies.

Local municipalities have played a key role, first in developing Eco-Town plans and then in supporting their implementation. Eco-Town plans are designed for "waste management", "development of recycling industries", "industry modernization", "environmental remediation", and "town planning and community development and engagement" (van Berkel et al., 2009b). After their plans were approved and designated as Eco-Towns, several local municipalities also initiated their own programs to support recycling projects through waste collection, information sharing, financial subsidies, and green procurement policies.

3.4. Local collaboration and partnership

A distinguishing characteristic of Eco-Towns is physical exchange of wastes and by-products among firms. Exchanges among Eco-Town projects were observed in 10 Eco-Towns (MoE, 2009). Such exchanges of reused resources are not limited to Eco-Town projects. For instance, van Berkel et al. (2009a) revealed seven material exchanges in Kawasaki Eco-Town, such as the use of waste plastics as alternative fuels in a cement plant and as reductants in blast furnaces. As we mentioned in Section 2, such physical exchanges, referred to as IS, can contribute to the stable operation of recycling facilities.

From an institutional point of view, local collaboration and partnerships among stakeholders in some Eco-Towns are actualized through coordination by an "Eco-Town committee"(Fujita, 2006). While the main actors in Eco-Town committees are recycling companies, the committees may also include municipalities, research institutions and universities, citizens, and non-profit organizations (NPOs). The committees' aims are to share information, to collaborate on research and project investigation, and to elaborate future plans (Fujita, 2006). In Kawasaki Eco-Town, for example, the NPO Liaison Center for Creation of Industry and Environment was set up in 2004 by a group of companies to solve resource recycling and energy problems (GEC, 2005). In Aichi Eco-Town, instead of a committee, there are resident coordinators in the study body who help match companies and consult on business plans (Fujita, 2006).

Residents were not actively involved in the planning stage of Eco-Towns. Community involvement has emerged in the form of facility tours of Eco-Towns and other educational and publicity programs. Several Eco-Towns have constructed facility tour centers. For example, Kitakyushu Eco-Town concentrates on raising awareness, arranging facility visits for about 80 thousand people annually (Fujita, 2006). These community efforts encourage residents to participate in recycling programs by raising their understanding of recycling processes and how recycled products are used to protect their living environment.

4. Methodology and data collection

4.1. Conceptual framework

Our aim in this paper is to examine factors influencing the amount of waste treated and the operating rates of recycling facilities in Eco-Towns because we are focusing on physical performance rather than economic viability. Fig. 1 shows the hypothetical relationship between the performance of recycling projects and various influential factors that fall into the three

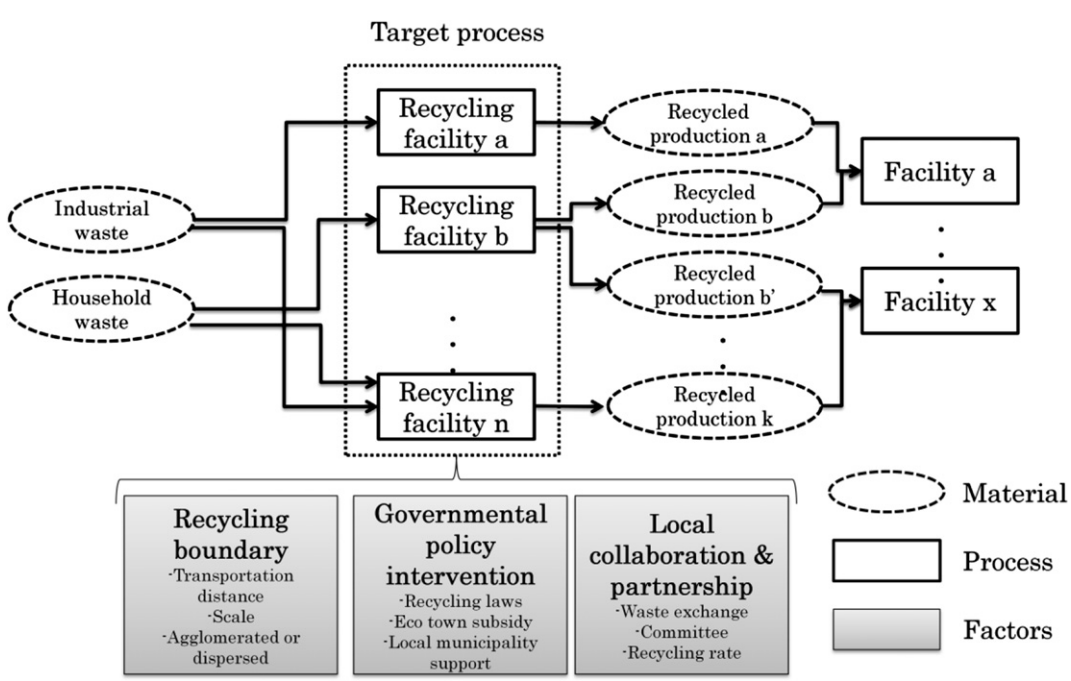

Fig. 1. Factors influencing the recycling process.

categories reviewed in the preceding section, i.e., recycling boundaries, government policy intervention, and local collaboration and partnership. In each category, we choose factors that could influence the performance of recycling facilities given data availability (Fig. 1).

4.2. Econometric model

To examine the factors influencing the amount of treated waste and the operating rates of recycling facilities we developed two liner regression models:

$$\begin{aligned}\mathrm{ATWST}_i = {} & \alpha_0 + \alpha_1\mathrm{AWCD}_i + \alpha_2\mathrm{APDD}_i + \alpha_3\mathrm{PCF}_i + \alpha_4\mathrm{INWST}_i \\ & + \alpha_5\mathrm{HHWST}_i + \alpha_6\mathrm{CPRI}_i + \alpha_7\mathrm{DMAG}_i + \alpha_8\mathrm{DMCPL}_i \\ & + \alpha_9\mathrm{DMHAL}_i\end{aligned}$$

$$\begin{aligned}\mathrm{ORATE}_i = {} & \beta_0 + \beta_1\mathrm{AWCD}_i + \beta_2\mathrm{APDD}_i + \beta_3\mathrm{PCF}_i + \beta_4 \mathit{INWST}_i \\ & + \beta_5\mathrm{HHWST}_i + \beta_6 \mathit{CPRI}_i + \beta_7\mathrm{DMAG}_i + \beta_8\mathrm{DMCPL}_i \\ & + \beta_9\mathrm{DMHAL}_i\end{aligned}$$

ATWST and ORATE above are the amount of waste treated. The operating rate ORATE is determined according to the following equation:

$$\mathrm{ORATE}\ (\%) = \frac{\mathrm{ATWST}}{\text{Planned Amount of Treatment}}$$

Table 1 summarizes the independent variables in the models above. The choice of independent variables was based on the conceptual framework above and on data availability. The first independent valuable in the category of recycling boundaries, *ratio of waste collection and product delivery within the prefecture*, is based on questionnaire results. To test the influence of scale, we chose *industrial waste generation*, *household waste generation*, *processing capacity,* and *capacity of heavy industries*, which capture most recycled products, to indicate the scale on the supply side, in facilities, and on the demand side. In Japan, household waste is, in principle, treated within the municipality where it is generated except for waste permitted by recycling laws to be moved over a boundary. Industrial waste can be treated within the prefecture, and the borders between prefectures are barriers due to license issues.

In the category of government policy intervention, we used dummy variables to represent the influence of specific recycling laws, namely *the Containers/Packaging Recycling Law*, *the Home Appliance Recycling Laws*, *the End-of-Life Vehicle Recycling Laws*, *and the Food Recycling Law.* A law dummy is set to equal to 1 if the major type of waste that a facility treats is designated by that law, and 0 otherwise. The recycling facilities treating auto shredder residue (ASR) and other parts and residues from automobiles fall under the *Automobile Recycling Laws.* The influence of the subsidy system is represented by the *rate of subsidies* compared to the total construction cost. *Waste collection support*, *financial supports*, *and green purchase* are introduced to model the efforts of local municipalities.

Variables that take local collaboration and partnership into account include whether *Waste exchange* exists in Eco-Towns, whether an *Eco-Town committee* functions, and the *recycling rate* in the city in which the facility is located. Due to limited information, we could not quantify the intensity of activities and the strength of the partnerships using data on such factors as informal linkages, the number of meetings held, and the number of visitors taking facilities tours.

Table 1
Definition of dependent and independent variables.

Variable	Definition and units	Sources
Dependent variable		
ATWST	Amount of waste treated by the facility in 2007 (ton/yr)	QR
ORATE	Operating rate of the facility in 2007 (%)	CQR
Independent variable (appropriate recycling boundary)		
RWCP	Ratio of waste collection within the prefecture in 2007	CQR
RPDP	Ratio of product delivery within the prefecture in 2007	CQR
PCF	Processing capacity of the facility in 2007 (ton/d)	(Fujita, 2006)
INWST	Industrial waste generated in the prefecture where the facility is located in 2007 (ton/yr)	(MoE, 2008a)
HHWST	Household waste generated in the city where the facility is located in 2007 (ton/yr)	(MoE, 2008b)
CPRI	Capacity of steel, non-ferrous, and cement industries in the prefecture where the facility is located in 2007 (ton/yr)	(JMD, 2009; CS, 2009)
DMAG	Dummy for agglomeration type, 1 if yes and 0 if no	(MoE, 2009)
Independent variable (government policy intervention)		
DMCPL	Dummy for containers/packaging recycling law, 1 if yes, 0 if no	(JCAPRA, 2008)
DMHAL	Dummy for home appliance recycling law, 1 if yes, 0 if no	(AEHA)
DMAML	Dummy for automobile recycling law, 1 if yes, 0 if no	(METI, 2010)
DMFDL	Dummy for food recycling law, 1 if yes, 0 if no	(MAFF, 2010)
RSET	Ratio of subsidies from Japanese government (%)	(Fujita, 2006)
DMPRS	Dummy for waste collection support, 1 if yes, 0 if no	QR
DMFS	Dummy for financial support from the municipality, 1 if yes, 0 if no	QR
DMGP	Dummy for green purchase from the municipality, 1 if yes, 0 if no	QR
Independent variable (local collaboration and partnership)		
DMWE	Dummy for waste exchange, 1 if yes, 0 if no	QR
DMCOS	Dummy for Eco-Town committee, 1 if yes, 0 if no	QR
RRCL	Recycling rate in 2007 in the city where the facility is located 2007 (%)	(MoE, 2008b)

Note: QR stands for questionnaire results. CQR stands for calculation from questionnaire result.

4.3. Data collection

Major sources of data included a questionnaire administered to Eco-Town recycling facilities and statistical data on the cities and prefectures in which the recycling facilities are located. The questionnaire was conducted in cooperation with "the Study Group for the Establishment of SMC (Sound Material Cycle) Blocks through Eco-Towns" organized by the MoE, which includes members from governments, and enterprise and research institutions. One of the coauthors (Fujita) had chaired the study group and conferred with us on our ideas in the selection of survey objects and the design of questionnaire. After getting feedback on a draft survey sent to local municipalities and facilities in four Eco-Towns (Chiba, Tokyo, Kawasaki, and Aichi), we revised the survey methodology and sent formal questionnaires to local municipalities again and to all the facilities in operation (Fig. 2). The survey asked questions in five

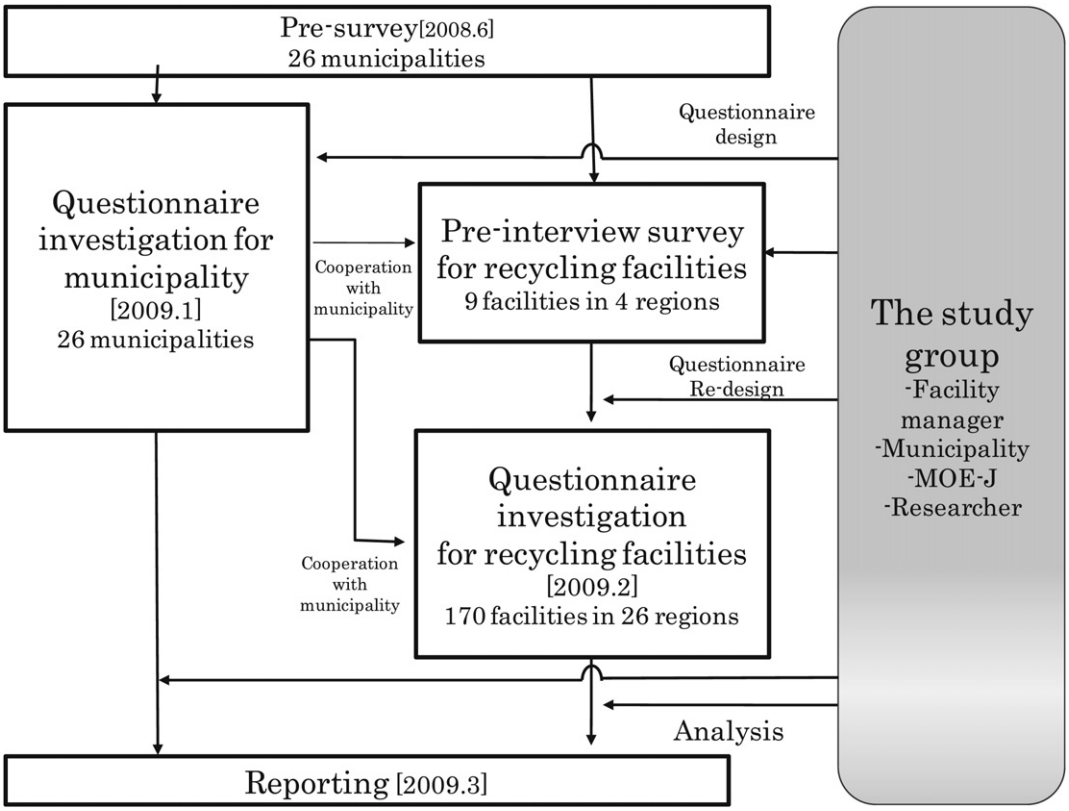

Fig. 2. Number of samples from each type of facility.

aspects, including (1) basic information of the facility; (2) amounts, types, sources or destinations of waste treated and products delivered; (3) energy consumption of processing; (4) utilization of by-products and waste heat; and (5) operational performance in terms of profitability, difficulties in operation and expecting supports. It is difficult to obtain detailed data on facility operation using a one-round questionnaire, and so the survey focused on material inputs and outputs. It also asked about support from local municipalities, operational performance of facilities, including facility size and profitability, waste sources, product destinations, and energy consumption. A total of 95 valid responses were collected from recycling facilities. Table 2 shows the responses grouped by major type of waste treated. Among the total responses, 55% were valid, and among facilities that received subsidies, 64% of responses were valid. The subsidized facilities tended to be a little more cooperative than those without subsidies.

Aside from the survey data, we obtained other information mainly from statistics and government reports. Table 3 gives statistical descriptions of all the variables in the regression models.

5. Results and discussion

Table 4 summarizes the parameters estimated in the two regression models. The adjusted R^2 of the two models are 0.506 for ATWST and 0.149 for ORATE. Both models are statistically significant at the 5% level. The adjusted R^2 for ORATE is relatively low. This could be caused by the failure to include factors in the model that could explain the variation of ORATE, such as technological and management levels, market competition, and level of cooperation among stakeholders.

The coefficients of variables in the recycling boundary categories provide some instructive results. *Ratio of product delivery within prefecture* (RPDP) has a negative relationship with ORATE. Looking into the data in detail, we found that operating rates for power, MSW, and RDF treatment facilities are, on average, higher than other facilities, while their RPDPs are lower. This result suggests that locating a facility close to large end users with stable demands contributes to a high operating rate. Because MSW is spatially diffuse and is mostly collected by municipal governments or contracted companies, geographical proximity to recycled products' end users exerts more significant influence on the operation of recycling facilities than proximity to waste generators.

Unsurprisingly, the coefficient of *processing capacity of facility* (PCF) is significant and positively related to ATWST. On average,

Table 2
Responses from recycling facilities.

	Number of facilities	Valid responses	Valid response rate
Plastics	39 (20)	19 (12)	49%
Food	19 (4)	7 (3)	37%
WEEE	17 (6)	9 (5)	53%
Demolition	11 (2)	4 (0)	36%
Ash	10 (8)	7 (7)	70%
Wood	10 (5)	9 (4)	90%
RDF	10	7	70%
Auto	9 (3)	3 (2)	33%
MSW	7 (1)	6 (0)	86%
Paper	7 (4)	3 (2)	43%
Power generation	5 (2)	4 (2)	80%
Shredder dust	4 (1)	2 (1)	50%
Oil	4 (1)	3 (0)	75%
ISW	3	3	100%
Glass	2	2	100%
Other	13 (4)	5 (1)	38%
Sum	170 (61)	93 (39)	55% (64%)

NOTE: numbers in brackets indicate facilities that received subsidies.

Table 3
Data description.

Variable	Unit	Sample	Min.	Max.	Ave.	S.D.
Dependent variable						
Amount of treated waste (ATWST)	ton/yr	93	1.00	140	75.2	27.5
Operating rate (ORATE)	%	93	0.10	117	53.7	28.0
Independent variable (recycling boundary)						
Ratio of waste collection within the prefecture (RWCP)		93	0	1	0.670	0.378
Ratio of product delivery within the prefecture (RPDP)		93	0	1	0.691	0.375
Processing capacity (PCF)	ton/d	93	0.8	1296	132	211
Industrial waste (INWST)	ton/yr	93	1,231,000	38,257,000	19,782,000	12,595,600
Household waste (HHWST)	ton/yr	93	1692	3,775,800	463,666	765,360
Capacity of primary industries (CPRI)	ton/yr	23	297,000	19,236,000	9,717,300	6,914,420
Agglomerated (DMAG)	Dummy	23	0	1	0.600	0.493
Independent variable (government policy intervention)						
Container & package recycling law (DMCPL)	Dummy	93	0	1	0.084	0.285
Home appliance recycling law (DMHHA)	Dummy	93	0	1	0.032	0.176
Auto recycling law (DMAML)	Dummy	93	0	1	0.063	0.244
food recycling law(DMFDL)	Dummy	93	0	1	0.032	0.176
Rate of subsidy (RSET)	%	93	0	50	15.7	20.3
Waste collection support (DMPRS)	Dummy	23	0	1	0.590	0.494
Green purchase (DMGP)	Dummy	23	0	1	0.716	0.453
Financial support (DMFS)	Dummy	23	0	1	0.653	0.479
Independent variable (local collaboration and partnership)						
Waste and by-product exchange (DMWE)						
Committee (DMCOS)	Dummy	23	0	1	0.832	0.376
Recycling rate (RRCL)	%	93	4.90	61.20	25.3884	10.96

Table 4
Parameter estimates for the two models.

Variable	Amount of treated waste (ATWST)		Operating rate (ORATE)	
	Coefficient	*t*-Statistics	Coefficient	*t*-Statistics
Constant	−16,343	−1.077	55.1	3.124***
Recycling boundary				
Ratio of waste collection within the prefecture (RWCP)	6803	0.816	−0.396	−0.041
Ratio of product delivery within the prefecture (RPDP)	9720	1.226	21.2	2.300**
Processing capacity (PCF)	112	7.836***	−0.011	−0.662
Household waste (HHWST)	2.40E−4	0.828	3.74E−7	1.083
Industrial waste (INWST)	−6.5E−3	−1.529	−5.37E−6	−1.083
Capacity of primary industries (CPRI)	2.30E−4	0.373	−4.24E−7	−0.575
Agglomeration (DMAG)	1604	0.268	6.80	0.976
Government policy intervention				
Container & package recycling act (DMCPL)	−939	−0.101	12.1	1.122
Home appliance recycling act (DMHAL)	5305	0.333	11.5	0.622
Auto recycling act (DMAML)	26,350	2.432**	20.3	1.614
Food recycling act (DMFDL)	6802	0.461	−12.7	−0.740
Rate of subsidy (RSET)	−1400	−0.096	−29.3	−1.722*
Waste collection support (DMPRS)	9014	1.383	1.08	0.142
Green purchase (DMGP)	8792	1.313	5.17	−0.664
Financial support (DMFS)	−9185	−1.131	−6.28	0.664
Local collaboration and partnership				
Waste exchange (DMWE)	−2762	−0.446	16.7	2.315**
Committee (DMCOS)	−2593	−0.346	−9.50	−1.088
Recycling rate (RRCL)	226	0.910	−0.022	−0.076
R^2-adjausted	0.506		0. 149	
F-statistics	6.238 (**0.000**)		1.892 (**0.030**)	

Note: *, **, ***Indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

expanding processing capacity by 1 ton would result in one-third ton of waste treated. PCF is not, however, significant in explaining ORATE. Larger scale does not necessarily lead to higher operating rates; however, it does contribute to operating rate stability as the operating rates of small facilities vary much more than large ones (Chen et al. 2012). Facilities locating in agglomerated Eco-Towns do not have performance advantages over those located in dispersed Eco-Towns. This result is consistent with results reported by Chen et al. (2012). The definition of an agglomerated Eco-Town in this study considers only the locations of recycling facilities under the same Eco-Town plan but does not necessarily mean intensive collaboration among closely located recycling facilities or with other industries. Being located close to other recycling facilities, who may be eventual competitors, did not prove advantageous in this study.

In the category of government policy intervention, the coefficient of the *dummy variable for automobile recycling act* (DMAML) is positive and statistically significant at the 1% level for ATWST. Because most ASR recycling facilities in Eco-Towns are closely related to non-ferrous industries, they have a technical edge in scale and a more stable demand for their recycled products. On the other hand, recycling businesses dealing with wastes, such as waste plastics, are in highly competitive markets where specific recycling laws do not ensure stable market demand for each recycler. Dummy variables for the other recycling laws do not appear to be significantly related to the operating performance of recycling projects.

The proposition that subsidies for facility construction make recycling projects able to perform better in operation is not proved in this study. The coefficient of *ratio of subsidy* (RSET) is not statistically significant in ATWST and is negative in ORATE. That is, facilities receiving 50% subsidies for construction are, on average, operating at 17% lower rates than non-subsidized facilities. One factor that may explain this is that since facilities that received subsidies employed state-of-the-art technologies and challenged innovative projects that would not be undertaken without the subsidies, they were more likely to face difficult operating conditions and markets than non-subsidized facilities.

In the category of local collaboration and partnership, only the coefficient of *dummy variable of waste exchanges* (DMWE) is positive at the 5% significance level in the ORATE model. This result suggests that facilities in collaboration with other recycling facilities in the same Eco-Town plan perform better in general than those without such ties. A direct benefit of such collaboration is increased waste supply in addition to collection from original sources. Collaboration also implies that facilities are not competing with one another for the same type of wastes, which would also contribute to stable operation. Because of limited data, we could not quantify waste exchange among recycling facilities. Whether increasing collaboration among recycling facilities would benefit their operational performance could not be tested with the current data, but may be a topic requiring more study in the future.

The results of the two simple regression models of recycling facilities in Eco-Towns offer several fruitful insights to aid in understanding the performance of recycling projects. First, geographical proximity to users of recycled products can contribute to high operating rates for recyclers. Although the supply of waste is directly associated with operating rates, it did not appear to be a significant factor in our models. Especially in developed recycling markets where logistic and super-regional coordination systems are already in place, the influence of transportation on the competitiveness of recycling facilities is relatively low. With similar technological efficiency, facilities that better deal with uncertainties in the demand market, and thus offer higher prices for waste stock, performed better. This result implies that when planning for a regional recycling system, one should pay sufficient attention to the demand for recycled products. For example, waste plastics recycling facilities should take good advantage of existing nearby primary industries as potential users of recycled products. Second, subsidies for construction of facilities do not contribute to improving the operating rates of recycling projects. It is undeniable that subsidies granted to select facilities enabled the completion of projects that otherwise would not be feasible. However, as the government does not now provide continued subsidies for operation, facilities receiving subsidies do not perform better but rather appear to endure lower operating rates than non-subsidized facilities. Third, collaboration rather than competition among recycling facilities helps improve their operating rates.

6. Conclusions

Compared with studies on waste separation and collection, the performance of recycling facilities is rarely comprehensively assessed in a quantitative manner. In this paper, we employed two simple regression models to analyze the amount of waste treated and the operating rates of 95 recycling facilities in Japanese Eco-Towns. We examined the influences of three important features: recycling boundaries, government policy intervention, and local collaboration and partnership. Results from the regression models suggest that, first, facilities located near the end users of recycled products tend to have higher operating rates. Second, although it is undeniable that subsidies for construction of facilities with leading technologies enable their operation in the initial stages, they are still confronted with operational difficulties. Third, cooperation rather than competition among nearby recycling facilities tends to lead to higher operating rates.

Recycling facilities are an indispensable component in urban and industrial systems for approaching closed loop material systems. In addition to factors we examined in this study, there are other factors that influence the performance of recycling facilities in different locations, some of which may be difficult to analyze quantitatively. Therefore, multi-disciplinary approaches are required to study various cases of performance across both innovative and conventional recycling facilities and activities.

In particular, two aspects require more scrutiny in the future. First, it is valuable to analyze the influence of recycling activities and Eco-Town policies on local communities in terms of building partnerships among residents, civil society, researchers, professionals, recyclers, industries, governments. In this study, we found that the existence of cooperation between recycling projects would improve operating rates. Because the influences are mutual, it is equally important to analyze influence of recycling projects on building relationships among stakeholders. For example, Kitakyushu city is conducting a survey for analyzing changes in consumers' PET recycling activity after informing stakeholders of impacts of exporting PET abroad versus utilizing it.[1] Green supply chain management, which focuses on recycling business activity and consumer behavior, would be useful for identifying such relationships among stakeholders. Second, feasibility of transferring the Japanese Eco-Town model to other countries is a critical issue. As Walkowiak and Bleischwitz (2007) pointed out that in Germany the Eco-Town model could contribute strongly to a structural transformation of heavy-industrial areas especially if they have "dense population, geographical closeness of industry, business and settlements and a highly developed transport infrastructure". As a case study, Chen et al. (2011) estimated the potential environmental gains if Japanese model transferred to Shenyang, a heavy-industrialized city in China. Additional studies are needed in the future to explore the ways by which the Japanese Eco-Town model, as well as other successful eco-industrial park models, can be adopted in different regions and countries.

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[1] Based on internal materials in the "Workshop on model projects on efficient use of arterial and venous industry clusters", in which the authors participated on November 10, 2011 in Tokyo, Japan.

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