

# Waste Management & Research

<http://wmr.sagepub.com/>

---

## Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston

Francisco Contreras, Satoshi Ishii, Toshiya Aramaki, Keisuke Hanaki and Stephen Connors  
*Waste Manag Res* 2010 28: 76 originally published online 26 November 2009  
DOI: 10.1177/0734242X09349417

The online version of this article can be found at:  
<http://wmr.sagepub.com/content/28/1/76>

---

Published by:



<http://www.sagepublications.com>

On behalf of:



International Solid Waste Association

**Additional services and information for *Waste Management & Research* can be found at:**

**Email Alerts:** <http://wmr.sagepub.com/cgi/alerts>

**Subscriptions:** <http://wmr.sagepub.com/subscriptions>

**Reprints:** <http://www.sagepub.com/journalsReprints.nav>

**Permissions:** <http://www.sagepub.com/journalsPermissions.nav>

**Citations:** <http://wmr.sagepub.com/content/28/1/76.refs.html>



Los Angeles, London, New Delhi  
and Singapore  
<http://www.sagepub.com>



© The Author(s), 2010. Reprints and permissions:  
<http://www.sagepub.co.uk/journalsPermissions.nav>

ISSN 0734-242X

Waste Management & Research

2010: 28: 76-93

DOI: 10.1177/0734242X09349417

# Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston

**Francisco Contreras**

Department of Urban Engineering, Faculty of Engineering, University of Tokyo, Tokyo, Japan

**Satoshi Ishii**

Center for Urban Regeneration, Department of Urban Engineering, University of Tokyo, Tokyo, Japan

**Toshiya Aramaki, Keisuke Hanaki**

Department of Urban Engineering, Faculty of Engineering, University of Tokyo, Tokyo, Japan

**Stephen Connors**

Laboratory for Energy and the Environment, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Despite some progress, municipal solid waste (MSW) still poses pressure on cities and remains one of the major challenges in environmental management. There is no single solution to the problem since the drivers behind MSW systems may vary significantly from city to city. In this context, the development of a common strategy to attain a sustainable management has been increasingly difficult. This paper presents an issue-driven analytical framework to evaluate the past, present and future MSW management strategy for the cities of Yokohama and Boston considering four driver categories while evaluating if the relevance of these drivers has changed over time. These categories represent: (i) legal drivers (*e.g.* laws and regulations); (ii) technology development and institutional drivers (*e.g.* available technologies); (iii) regional and international drivers (*e.g.* solid waste flow as recyclable resources); and (iv) socio-economic drivers (*e.g.* population trends and public awareness). The analysis indicated that solid waste management capacity for both cases was under stress due to different reasons. In the case of Boston, the moratorium for disposal facilities played an important role while increasing population was a key driver for the city of Yokohama. The future management scenario suggests that various waste-to-energy alternatives and strong solid waste reduction policies will play a key role for Boston. In Yokohama, a shift on waste composition and generation triggered by a demographic change may open the path for new technologies while also considering the international demand of solid waste as a recyclable resource.

**Keywords:** integrated solid waste management, Boston, Yokohama, driver categorization, legal drivers, international-regional drivers, technology development and institutional drivers, socio-economic drivers

---

## Introduction

Over the years, the management of municipal solid waste (MSW) has developed as a response to the increasing amount of waste being generated, and to provide proper treatment and disposal according to each city's needs. Indeed, several aspects ranging from public environmental consciousness to governmental policies have also played an important role as drivers influencing solid waste management. Thus, defining a

common strategy to analyze these drivers can be itself difficult, mostly due to the differences between city's realities and waste management. Some authors have defined drivers as the forces that lead to pressures on the environment or as anthropogenic activities that may have an environmental effect (EEA 2004); also, drivers are described as factors not only limited to certain type of pressures but also to social and eco-

**Corresponding author:** Francisco Contreras, Department of Urban Engineering, Faculty of Engineering, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

E-mail: [pineda@env.t.u-tokyo.ac.jp](mailto:pineda@env.t.u-tokyo.ac.jp)

Received 3 June 2008, accepted in revised form 20 August 2009

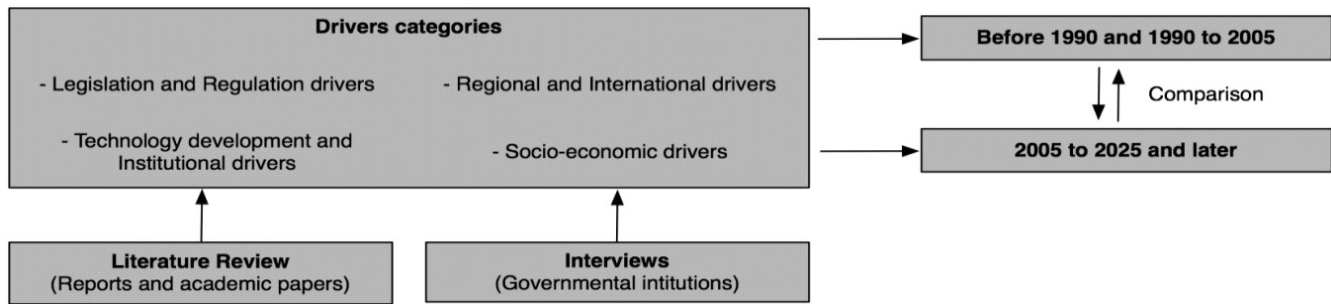


Fig. 1: Issue-driven analytical framework.

conomic changes (Desmond 2006). For example, population growth and changes in solid waste composition are key drivers influencing or characterizing a city waste management while the orientation of a city recycling scheme may depend on several factors, ranging from physical constraints, knowledge about recycling and availability of facilities (Tonglet *et al.* 2004) to the income associated with the social strata (Binder & Mosler 2007). In some situations, market demand for solid waste as resource can be also described as a driver; for example, the import of organic waste for district heating purposes in Sweden has also had a key function by influencing solid waste flows and composition in other countries (Ericsson & Nilsson 2004). However, little is known if the role of these drivers has always been the same. Thus, identifying these drivers and how they have influenced solid waste systems is an important step in understanding the future direction of a sustainable solid waste management plan.

In terms of sustainability and solid waste, Woolridge *et al.* (2005) defined sustainable management as an environmentally effective, economically affordable and socially acceptable system. White *et al.* (1999) highlighted the need for a sustainable system to be an integrated management process, considering aspects such as waste collection and an efficient sorting system, whilst emphasizing material recycling, biological treatment of organic materials, thermal treatment and disposal. McDougall *et al.* (2002) characterized sustainable solid waste management in terms of ensuring public health by preventing the spread of disease and safety of workers and recognizing the need to consider the following aspects:

1. Environmental effectiveness by taking into account the reduction of environmental burdens of waste management, either by the reduction of air, water and land emissions.
2. Economic affordability in order to operate at a cost acceptable to the community, including all private citizens, business and government.
3. Social acceptability – a management system operating in an acceptable manner for the majority of people in the community, involving stakeholders groups.

In summary, MSW management has to be studied from a general perspective in order to include aspects such as social and technological issues.

In this paper, we provide a framework of analysis for contributing to these needs. The analytical framework consists on four general driver categories representing different areas related to solid waste systems, as well as considering aspects of sustainable management. This framework provides the opportunity for cross-category analysis, as it allows the comparison of drivers along the categories first by considering how these have taken part in development of solid waste management and second by evaluating if their importance over the years has changed.

This research begins by describing four general categories of drivers based on their historical context and how these have influenced the development of MSW management. These two cases examine the development of solid waste management for the cities of Boston (Massachusetts, USA) and Yokohama (Kanagawa, Japan), using an analytical framework which compares these categories of drivers over two time periods (the recent past and the near future). This analysis provides a better understanding, of how the different drivers have influenced the past development of their respective solid waste management systems, and how these influences may likely change in the future.

### Issue-driven analytical framework

The application of the issue-driven framework to study a MSW system involves two main approaches as shown in Figure 1. The first approach, ‘driver categories’, consists of the description of a solid waste system based on four categories where the drivers are grouped and analyzed according to their sphere of influence and similarities. For example, drivers related to public health and environmental protection may be allocated to categories describing regulations or socio-economic aspects, while public awareness may be better represented by a category focused on socio-economics. On the other hand, better treatment and disposal technologies for solid waste could be considered in a category representing technological innovation.

The second approach, ‘analytical framework’, involves the analysis of these drivers considering two time frames to provide a better understanding of how solid waste management has and could develop in the coming years. The components of the driven analytical framework are further described below.

### Driver categories

The following key driver categories have been described based on literature review and discussion with other researchers.

1. Legislation and regulation drivers.
2. Technology development and institutional drivers.
3. Regional and international drivers.
4. Socio-economic drivers.

#### Legislation and regulation drivers

This category represents drivers describing the attributes and obligations of municipalities as institutions responsible for the collection, treatment and disposal of solid waste; in some cases, these consist in the selection of a disposal site. For example, the designation of disposal sites in the US in the 1930s was a function of the local government and intended to establish a controlled solid waste disposal to restrict scavenging activities. Furthermore, the application of controlled tipping was considered a factor influencing the first sanitary landfill practices. Later, in 1960, the adoption of sanitary landfill as the means of disposing of municipal waste was viewed as economical and a sanitary method to reclaim land which influenced solid waste management (Tiarr 1996). In 1965, the Solid Waste Act was enacted to constitute the first modern regulation in the US, later developed into the actual regulatory system.

In Japan, solid waste attracted attention as a social problem in the 1970s due to the general disposal space constraints the system was under and the related health problems with solid waste. As a result, improvement in solid waste collection and infrastructure in general were promoted throughout the country supported by strong legislation. Later, regulations were also adopted in the form of environmental protection focused on environmental problems related to solid waste and resource recovery. In a broader context, local and international agreements such as the targets for the Kyoto Protocol could provide the conditions for an increase in waste-related renewable energy production and carbon dioxide reduction.

#### Technology development and institutional drivers

Technological development during industrialization was an important driver in shaping the earlier stages of solid waste management. Industrialization attracted population to urban centres generating large amounts of waste which eventually was synonymous with air, water and soil pollution. As an answer, waste management was institutionalized supported by the development of treatment and disposal technologies. Among these technologies, the networks for the supply of pure water and sewage removal were the top priority for the US in the 1870s (Tiarr 1988); in the late 1890s, industrial solid waste, municipal waste and manure among others were the main targets for technological development aiming at reducing aesthetic nuisances and public health menaces (Melosi 2000).

In the 1930s, most of cities in the US moved towards an organized waste management based on a series of practices and technologies. Some of these, which played the role of

drivers during that time, were mechanical sweepers, compactor garbage vehicles, scales to record the amount of waste collected and disposed, and engineering drainage for the removal of water from waste disposal sites (Melosi 2000; Montville 2001).

The application of new technologies was also supported by several cities and smaller communities moving to local partnerships and regional agreements for municipal waste collection and disposal services, permitting local governments to collaborate on providing efficient waste management services (Melosi 2000). Although waste to landfill was the main practice used for solid waste disposal, the introduction of incineration as a 'waste-to-energy' technology drove waste management in a new direction. However, in some situations, the application of 'waste-to-energy' technologies was partially limited due to the cheap value of land. In spite of this scenario waste incineration for energy generation has become important for local economies, with emphasis on improved energy efficiency rates (Gohlke & Martin 2007).

#### Regional and international drivers

In recent years, international trade of recycled materials has increased and become an emerging driver for solid waste management. The outflow of recyclable waste from developed economies to economies in development such as China and the rest of Asia has increased influencing the composition and amount of solid waste flows with repercussions for the local recycling or incineration plants. Exports from the US and European Union countries to this region have also been growing as part of the needs of the Asian economies. Chinese customs statistics for 2004 reveal a total import of 4.1 million tonnes of plastic waste, 12.3 tonnes of used paper, and 10.2 million tonnes of aluminium scrap, accounting for more than 90% of imports from Asia (34.8%), Europe (15.2%), North America (34.2%) and neighbouring countries (8.3%) (Terazono *et al.* 2004). According to the Japanese Institute of Developing Economies (IDE 2005), the import of recyclable materials by major Asian nations has increased over the past 15 years; in the case of paper waste, the amount imported by China and Thailand increased from 423 and 214 thousand tonnes in 1990 to 9382 and 1098 thousand tonnes in 2003, respectively. In the case of some European countries, the trade in waste has also focused on yellow waste (mixed fraction of wood, paper, rubber, plastics and MSW) for energy recovery purposes. In the past 8 years, the amount of imported waste from other EU countries has increased from around 100 thousand tonnes compared to 1996, such as the case of waste imported from France with 500 thousand tonnes in 2003. Other examples also involve the cement industry in Denmark where waste imports from Germany and Norway are carried out for the combustion of cement kilns (Rasmussen & Reimann 2004).

#### Socio-economic drivers

The analysis of socio-economic related issues has become of a great importance in the development of MSW policies. In

the case of growing Asian cities, a rapid increase in the urban population with ~4% annual growth (~35% of the total population resides in urban areas) together with rapid urbanization and economic development has contributed to an increase in consumption rates and, therefore, the amount of solid waste generated. Furthermore, consumption rates have greatly accelerated due to the rapid population growth over the years in India and China (National Research Institute of China 2003; 2004). For example, higher waste generation in Sri Lanka is due to increased consumption patterns as well as the movement of population to urban areas; in the case of Thailand, over 23% of the population located in urban areas and the rate of economic growth has caused an increase in daily waste generation rates per habitant. In some situations, it may also be possible to assume future changes in solid waste composition for economies in transition triggered by the increase in plastic utilisation (Tchobanoglous *et al.* 1992). In terms of waste management, countries with growing economies will mostly experience management constraints; in China, a major pressure over the management is expected since the country policy aims to increase the urban population from 30% to 50% by 2010 (Visvanathan & Trankler 2004). As for already developed economies such as Japan, solid waste management is also becoming overwhelmed by population growth and economic development (Mendes 2003).

On the other hand, public health has been one of the factors behind the development of solid waste management. Historically, waste littering created favourable conditions for rodents and other vectors to spread diseases. For example, the plague in the 14th century in Europe may be partly attributed to the practice of littering waste on unpaved streets, roadways and vacant land in cities (Tchobanoglous *et al.* 1978). In some Hispano-American colonies, public health concerns reflected on waste management, as the collection of solid waste from land-owners or communities was dumped on the land either uncovered or buried. According to Garrick (2004), the rise in public concern in the US about the quality of the living environment and health-related issues was behind the development of the sanitation structure for drinking water, sewerage and solid waste in the industrial age. Public concern is also represented by the 'not in my back yard' syndrome (NIMBY), which became evident when residents resisted the location of open dumps or incinerators in their neighbourhood due to the lack of sanitary and environmental considerations (Melosi 2000). Public concerns and awareness play an important role as drivers in the implementation of waste policies, where the application of a recycling-oriented management requires understanding of the social interest and barriers associated with new separation and treatment technologies (Coggin 1994; Schultz *et al.* 1995). For instance, Stewart *et al.* (2001) define, in a comparative study, the different mental behaviours associated with recycling and reduction of solid waste generated.

In comparison to earlier work on solid waste drivers, we performed our analysis based on these categories involving a variety of aspects common to both cases of study. In recent

years, several authors have characterized the development of solid waste systems based on different drivers, describing their role in solid waste systems from an historical context to current practice. In particular, Wilson (2007) identified public health, environmental protection, resource value of waste and public awareness as separate groups of drivers behind the development of solid waste management. Nielsen (2003) concluded that shortage of treatment capacity and the existence of a waste incineration tax were additional driving forces affecting the gate-fee differences and thus import/export. On the other hand, Rudden (2007) described the use of policies such as 'pay as you throw' and regulatory instruments as the drivers behind a better environmental practice and the implementation of an integrated waste management system in Ireland. Although there have been several studies in this regard, the formulation of driver categories will be according to the characteristics of the solid waste system. In some situations, public health may be chosen as a representative driver category behind the development of solid waste; from another perspective, a category describing laws and regulations could also represent the influence of public health, environmental protection and other relevant drivers in the development of waste management.

#### Analytical framework

The analysis of a solid waste system based on the driver categories consists of four relevant steps (Figure 1). First, a step involving the consultation of official reports, articles and documents from non-governmental organizations and/or institutions in order to characterize the management of MSW in the area. As a second step, the characterization of the solid waste scenario is further supported by interviews with governmental officials associated with solid waste while reviewing relevant literature and data. The third step refers to the analysis of the drivers influencing waste management over the past 15 years according to the four categories described in this study.

However, there is still the question of how MSW management systems will develop in the near future and if the drivers will still play a similar role. For example, Olofsson *et al.* (2005) described how the driving forces for the import of waste for energy recovery in Sweden may change in the future, where a tax on waste incineration is being investigated providing the means for the development of alternative options for energy generation. Moreover, the adherence of European countries to the Kyoto Protocol targets could provide the conditions for an increase in renewable energy production, improving the competitiveness of waste-derived fuels in comparison to fossil fuels and influencing the future fees related to waste import. Therefore, the fourth step describes the comparison of driver categories considering two time periods: the first, before 1990 and 1990–2005, involves the past and actual drivers influencing MSW management; the second period, 2005–2025 and future, analyzes the drivers that could influence the development of MSW in the near future. This comparison aims to highlight changes in the importance of these drivers, where, in some situations, the influence of a

driver over solid waste management was weaker, moderate or stronger during one of the time periods. Under these conditions, the changes in a driver's importance are assessed in a radial chart representing the two time periods. The importance of a driver is expressed using an ordinal scale from 0–3 selected for plotting purposes (0, no influence; 1, weaker influence; 2, a moderate influence; and 3, a strong influence). For example, if the role of any particular driver in first time period has been weaker, the value of '1' is assigned, while for the second time period, it could be possible to assume a similar or different behaviour depending of the scenario. Thus, a value ranging from 0–3 could be assigned.

### Drivers for Boston city MSW system

Boston is located in the north-east of the US, on the east coast of the State of Massachusetts. Like most of the cities in the State, the MSW system is mainly characterized by the presence of a series of incineration plants and landfill sites dispersed within the State. Municipal solid waste can be mainly divided into commercial and household fraction, where the latter accounts for 45% of the total. Other types of non-hazardous industrial waste, sewage sludge, medical waste and others are managed by specific contractors and not considered as MSW (DEP 2000). Depending on the county or city, solid waste collection is either carried out by private contractors or local municipalities, making it difficult to define the amount of household solid waste treated or disposed of by each county or city. It also influences the treatment or disposal method followed, since common practice involves the incineration of solid waste as treatment before disposal but, in some situations, solid waste is directly disposed of in landfills. In order to have a representative value for MSW for the city of Boston, an analogy was drawn with the amount of solid waste treated and disposed of by the State of Massachusetts. This gave a value of 289 thousand tonnes of MSW for the city of Boston in 1999 (DEP 2000) from which 34% is recycled, 37% is treated by incineration, 15% is disposed of in landfills and 14% is exported to other states.

### Legislation and regulation drivers

#### Before 1990 and 1990–2005

In response to the increasing amount of solid waste generated, the Solid Waste Disposal Act (SWDA) in 1965 aimed to support the management of solid waste through development of research projects and investigations among others (EPA 2006). The act also provided the possibility to share the cost of these studies with other states and to develop waste management plans. Later, in 1976, the Resource Conservation and Recovery Act (RCRA) was one of the initial steps to define particular guidelines for the management of municipal and hazardous solid waste considering air pollution, human health and environmental protection. Although the guidelines governed the disposal of waste, these introduced the first requirements as pollution control technologies for transfer stations and waste incineration plants (EPA 2006). During the same period, State regulations were also focused

on tackling illegal waste dumping and to support the development of criteria for selecting treatment facilities and landfill sites. In particular, the role of 310 Code of Massachusetts Regulations (CMR) 16.000 (later updated in 2001) was to define the conditions and requirements for the selection of disposal sites, as well as the limitation on their numbers with implications for the treatment and disposal of waste introduced in the 1980s (better known as the 'Moratorium' for placing new facilities and expanding actual landfill sites).

In terms of waste reduction, regulations were focused to prevent waste being generated, to improve waste recycling and to ban the disposal of certain types of waste, such as asphalt, pavement, bricks, concrete, wood, and metals. This was also supported by a series of programmes and policies such as the Beverage Container Redemption or Bottle Bill in 1983 aimed at formalizing the recycling of plastic containers, as well as to support the development of other schemes such as 'pay as you throw' (PAYT) and compost bins (DEP 2000). At the commercial level, recycling programmes were promoted to encourage the composting of food waste from supermarkets and restaurants (DEP 2004). By the 1990s, the State master plan for waste management included guidelines for solid waste management for the next decade with milestones for solid waste recycling of 31% (DEP 2000).

#### 2005–2025 and future

In the coming years, the State reduction targets for solid waste may keep increasing since, in 1999, a total of 53% was reduced in comparison to a 60% in 2004, yielding an estimated reduction of 2% of the waste landfilled (DEP 2000). Moreover, the application of PAYT programmes may reach a higher number in the future since municipalities following this scheme increased from 94 to 116 municipalities by 2004 including 30% more of the total population in order to reach the State overall reduction target of 38%. As for the private sector, partnerships with local government will reduce the amount of waste being generated. Other examples include an improvement in the regulatory system to support resource use and re-use, such as the case of extended producer responsibility, prohibitions on disposal or mandated recycling of certain types of post-consumer and/or industrial waste, and a greater reliance on corporate environmental management systems (EPA 2003). Regulations supporting waste reduction policies may have a predominant role supporting recycling schemes with the private sector, in particular for the case of paper, cardboard and organic waste, which has the potential for more than 75% waste reduction (Goldstein 2003). In addition, legislation restricting the State disposal capacity may continue to play a relevant role since actual projections for solid waste generation limits the disposal capacity by the year 2007 (Table 1) (DEP 2005).

### Technology development and institutional drivers

#### Before 1990 and 1990–2005

Late in the 1970s, the management of municipal solid waste was undergoing several changes; communities in the US

Table 1: Legislation and regulations as drivers for waste management in Boston case study.

Time period	Drivers
Before 1990 and 1990–2005	
(1965)	Solid Waste Disposal Act (SWDA)
(1976)	Conservation and Recovery Act (nation wide)
(1980s)	Environmental code towards solid waste reduction
(1980s, actualized in 2001)	Moratorium for new treatment and disposal facilities for solid waste (310 CMR 16.000)
(1980s)	Environmental code for the definition of treatment and disposal facilities
(1995)	Solid waste 'Master Plan'
2005–2025 and future	
	Solid waste 'Master Plan'
	'Pay as You Throw' (PAYT) policy
	Lift of moratorium on solid waste ban
	Policy developed among local government and private area for waste prevention and reduction
	Policy for commercial organic waste use and stronger waste recycling
	Policy towards extended producer responsibility

were faced with solid waste problems as local landfill capacity was starting to reach its limit. Policies were focused on reducing the amount of waste going to landfill based on the adoption of new practices and technologies. Waste-to-energy technologies, such as incineration, became attractive first due to the capacity of the process to reduce the volume of waste being landfilled and second for the possibility to produce energy in the form of heat and electricity – an economic benefit while complying with the regulatory system of the time (Gohlke & Martin 2007). Waste incineration has been widely applied within the State of Massachusetts with over 25% based on refuse-derived fuel (RDF) (Williams 2004) the process allows for the preliminary sorting of combustible and non-combustible solid waste with the recovery of recyclables before the burning process (White *et al.* 1999). Nevertheless, air pollution is one of the major drawbacks associated with this kind of technology, with particular concerns about dioxin emissions.

#### 2005–2025 and future

Despite the fact that more than 50% of MSW is incinerated in the State of Massachusetts, higher numbers could be expected in coming years as incineration becomes mandatory

with influence on the number of treatment plants. As for the coming years, waste management in Boston may focus on improving the efficiency of plants for energy generation (*e.g.* adoption of fluidized beds) and reducing the environmental loadings of the process while applying resource recovery (*e.g.* metals). For example, the disposal of solid waste into landfills has been further restricted in some European countries creating the possibility to improve further the efficiency of waste-to-energy plants (Olofsson *et al.* 2005; Gohlke & Martin 2007).

Nevertheless, energy generation from renewable sources could also play a relevant role. Table 2 shows the energy generation scenario from the perspective of renewable technologies between the years 2000–2005 for the State of Massachusetts, where waste incineration and landfill gas share more than 60% of the energy generated, followed by 32% from hydro-electric power plants and 5% from biomass and wood waste (EIA 2005). Under these conditions, it could be possible to assume that technologies, such as the co-firing process and biogasification, will start to play a more relevant role than waste-to-energy options. In the case of landfills, energy recovery from landfill gas could become common practice as part of the aim for the reduction of greenhouse gas (GHG)

Table 2: Renewable energy generation for the State of Massachusetts by source. 2000–2005 (Energy information administration US).

Period	(Thousand kW h <sup>-1</sup> )			
	Hydroelectric conventional	MSW/landfill gas	Other biomass	Wood/wood wWaste
2000	702,504	1,929,386	24,184	129,768
2001	694,267	1,929,386	202	129,768
2002	853,159	1,917,587	851	106,687
2003	993,205	1,899,196	1,619	114,336
2004	993,205	1,899,196	1,619	114,336
2005	1,041,950	1,884,193	26,378	120,027

emissions. Other waste-to-energy approaches could include the transformation of solid biomass at high temperatures in a oxygen-free environment into liquid fuel or bio-oil in a process called liquid pyrolysis and district heating through biodiesel co-generation, such as the example of the Allston-Brighton community building located in Boston (DEP 2004).

Furthermore, the application of waste-to-energy options could move towards the use of specific types of waste in order to diversify the sources of energy. For instance, biomass from MSW has a large potential for expansion, sharing around 30% of the sources of biomass from residues (Fallon *et al.* 2002). Other examples include the implementation of biogasification and composting in conjunction to support a scenario where organic waste is banned from the actual incineration and disposal practices (*e.g.* Sweden and Germany solid waste management). Moreover, it could be possible for biomass to be considered as a trade resource for the generation of energy with a clear example in district heating in Sweden where the demand for certain type of solid waste has included other countries in the form of solid waste export, influencing the recycling market (Olofsson *et al.* 2005).

**Regional and international drivers**

**Before 1990 and 1990–2005**

Over the years, the increasing amount of waste generated together with the restricted disposal options within the State boundaries provided the circumstances for the introduction of solid waste disposal in surrounding states as part of the solution to the solid waste problem. As shown in Figure 2, the total amount of solid waste generated at the state level has increased from about 10 million tonnes to almost 13 million tonnes from 1995 to 2005. More than the 80% of the solid waste generated has been absorbed by the State management capacity which includes composting, recycling, incineration and landfilling. Yet, the difference between solid waste generation and the State management capacity represents the net value of solid waste to be disposed of in other states, which has increased over the years from 470 thousand tonnes in 1995 to 1147 thousand tonnes in 2005 and an estimated of

2869 thousand tonnes for 2025 (DEP 2000; DEP 2006). Since the movement of solid waste for disposal takes place at the interstate level, no reference is made regarding international regulations for the export of waste to other countries. However, it is important to emphasize the relevance of this driver not only for representing an option for solid waste management but also for highlighting the dilemma between solid waste generation and disposal within the same geographical boundaries.

**2005–2025 and future**

Despite the actual solid waste reduction policies, solid waste disposal in other states will continue to play an important role for solid waste management in Boston. By contrast, the value of solid waste as a recyclable resource has increased over the past years, favoured by international demand, such as the case of scrap paper exported to countries such as China and India. According to the Massachusetts Environmental Agency (DEP 2006), the increasing demand for scrap paper may promote the recycling of waste in coming years with approximately 1.1 million tonnes of paper being recycled in 2004. Furthermore, the value of recycled paper has increased from US\$80 to US\$120 per tonne, forming a complex scenario for the actual and future paper companies within the State due to the competition from prices (Greve 2005) and the lower cost associated with paper sorting in countries like China (US\$3.40 a day in comparison with the US worker at US\$5.15 an hour). These circumstances may provide the basis to promote an international trade in paper scrap even if this results in the decline of local recycling companies.

In terms of GHG emissions, reduction targets could also play an important role as a driver in coming years with focus on the amount of GHG emissions and movement towards energy efficiency systems (Hammel *et al.* 2004).

**Socio-economic drivers**

**Before 1990 and 1990–2005**

As part of the drivers influencing the development of solid waste systems, socio-economic aspects can be described from

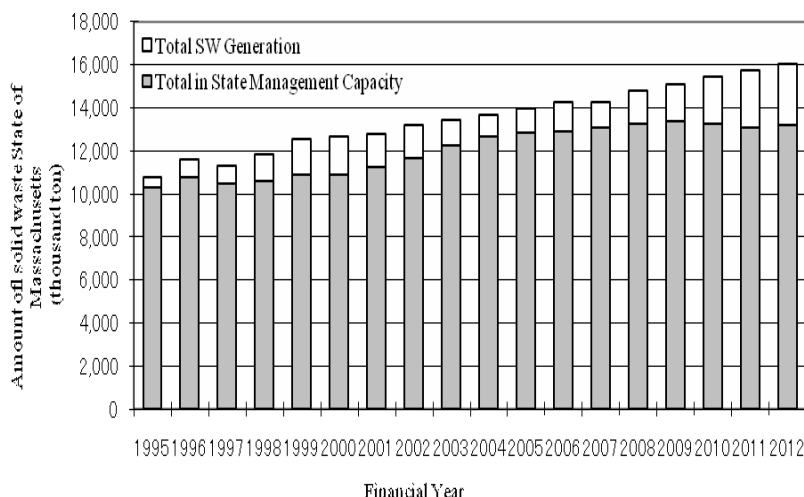


Fig. 2: Projections for MSW management in Massachusetts. (A) Period 2001–2005; (B) period 2005–2010. Source: DEP 2000–2005.



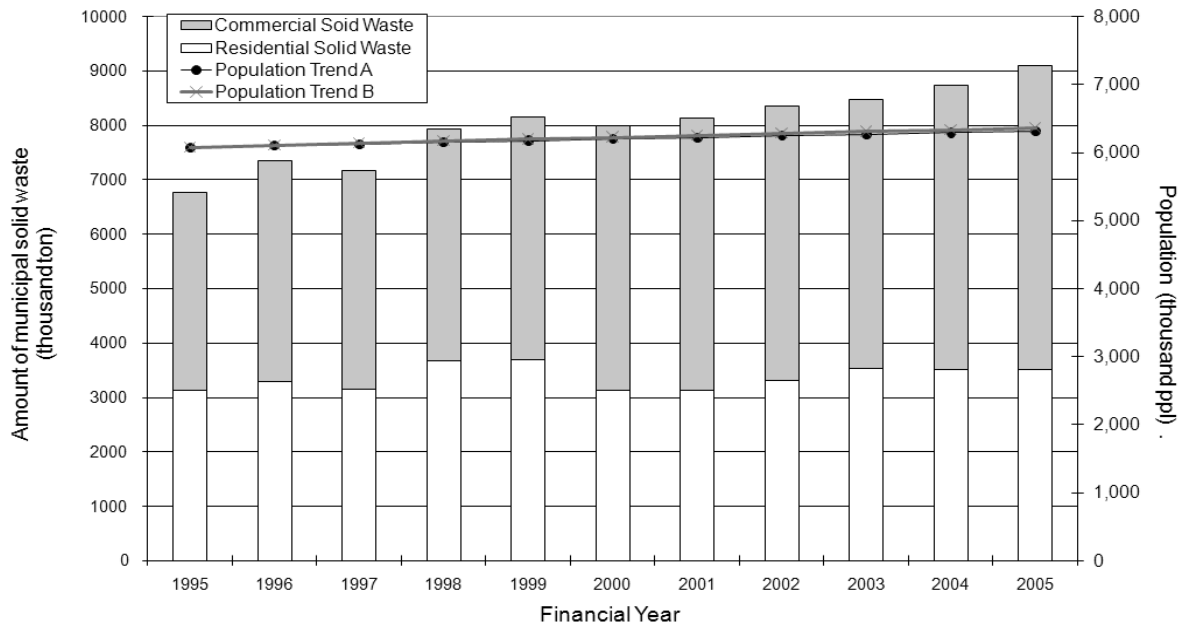


Fig. 3. Amount of municipal solid waste and population trends for the State of Massachusetts (MAPC, 2006).

different perspectives. For instance, how solid waste composition or population growth will influence the selection of treatment technologies.

In the case of Boston and the Massachusetts area, population growth has played an important role by directly influencing the amount of household solid waste produced. Figure 3 shows the trends for the generation of residential and commercial solid waste at the State level between 1995 and 2005, while considering population growth for the same time period. There is a positive trend for the amount of solid waste generated between these years where in 1995 around 6.7 million tonnes were accounted in comparison to 9.0 million tonnes for the year 2005 (DEP 2005; Bureau 2006). This increase primarily corresponds with a positive population growth and changes in society consumption patterns due to increased personal income which also includes restaurants, merchandise and food stores (Hockett *et al.* 1995).

In the case of Boston, the amount of MSW has increased over the past years in response to the increase of MSW generation rates and population growth. In 1999, around 248 thousand tonnes of household solid waste were produced by about 574,000 inhabitants; in 2004, around 267 thousand tonnes of household solid waste were generated by 569,000 inhabitants (MAPC 2006).

In comparison to previous years, the role of public awareness in MSW has gradually increased. According to Altschuler (2005), policies towards solid waste recycling and disposal are among the areas with higher criticism in the US as being one the largest sources for anthropogenic methane emissions. In the case of the city of Boston, public awareness is partially driven by the possible ecological effects on the environment due to waste management activities (Capone 2000; Capone 2003), such as the episode of mercury contam-

ination from incineration plants resulting in action by citizens and environmental activists (Lajoie 1998).

#### 2005–2025 and future

Among the future drivers influencing the management of municipal solid waste, the acceptance of future disposal facilities may become a relevant aspect in coming years. Public perception of poor practices in the past (burning dumps, polluting incinerators) has led to the inevitable NIMBY reaction (Wilson 2007). Episodes of air pollution due to waste transportation and the contamination of water courses by mercury among others raised the awareness of citizens (Capone 2000; Graham 2003). Moreover, public awareness of the possible health and environmental dangers related to an increase in the amount of solid waste to be incinerated are present in the community (Capone 2003). On the other hand, public awareness can also be described as the possible influence of society on raising the actual gate fees in order to reduce the amount of solid waste disposed.

Another key socio-economic driver is the influence of public participation and social behaviour in solid waste generation. For instance, the implementation of waste reduction initiatives may depend on the adherence of the society to recycling schemes as well as continuity consumption behaviour, which will influence the adoption of certain technologies. In practice, home composting in the city of Boston is carried out by the majority of the population with access to gardens, by providing the organic waste to neighbours, or by delivery to the nearest composting area (DEP 2006). According to a survey of the Boston area, residents in the area favour the development of separation and recycling programmes aimed at reducing the amount of solid waste disposed of even if there are associated costs (Contreras *et al.* 2008).

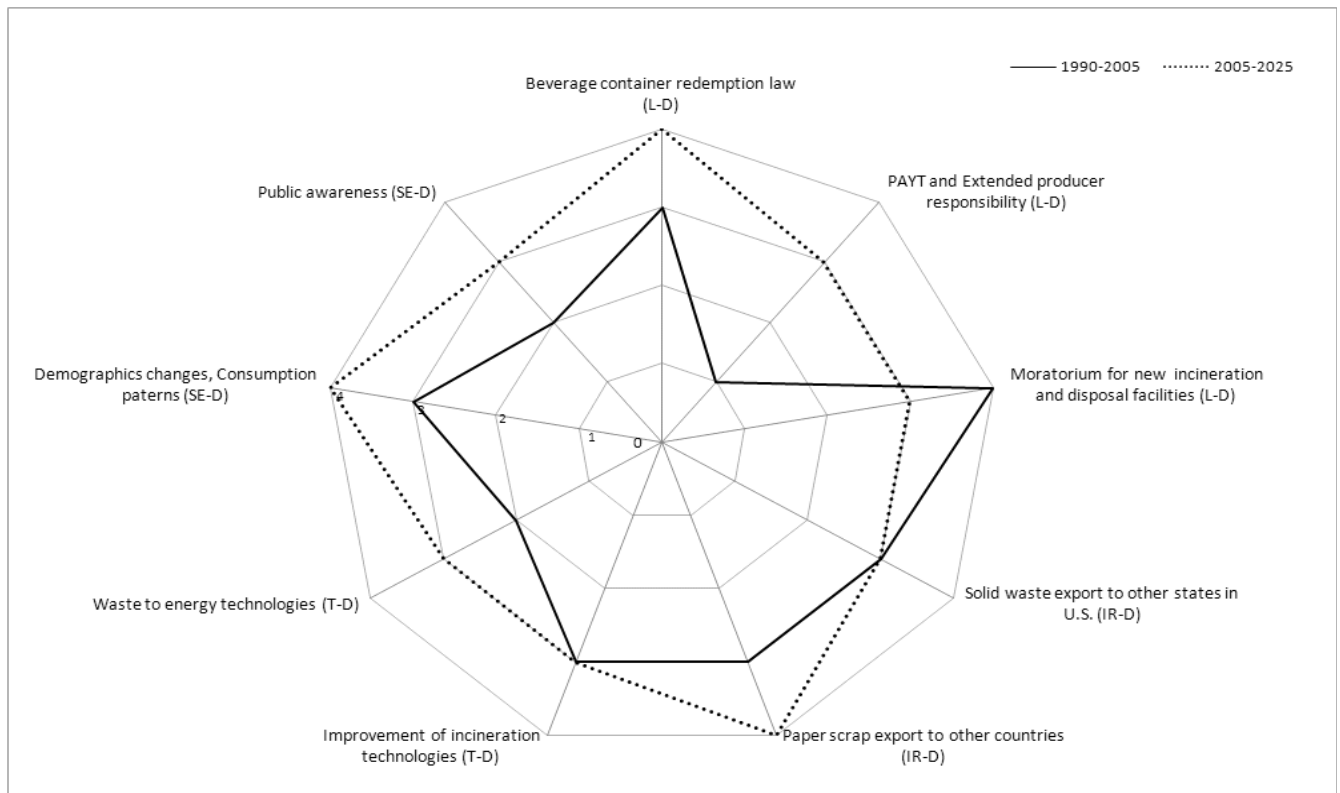


Fig. 4: Radial chart showing changes in importance for Boston drivers over two time periods. L-D, legislation and regulation drivers; T-D, technological; development and institutional drivers; IR-D, international/regional drivers; SE-D, socio-economic drivers.

### Shift over the two time periods

During the formulation of the State waste management plan in the early 1990s, particular emphasis was given to waste incineration and the landfill future capacity constraint. Over the years, the limits on disposal capacity within the State have become evident and the export of waste has been included in the management strategy. Meanwhile, efforts have been made to develop regulatory instruments for the State of Massachusetts to support the implementation of policies to reduce the amount of solid waste to be disposed. The use of beverage container redemption and extended producer responsibility laws aim support and strengthen the recycling market possibilities. Nevertheless, it is necessary to consider the consequences of a further increment in the actual trade rates of recyclable waste (as resources) either at the national or international level. For example, the permanence of local industries which use recycled paper in their process (e.g. mills) may be under pressure from the market demand for paper scrap from other economies such as China, India and Indonesia.

Further implementation of PAYT policies would influence the waste generation trends by discouraging residents from solid waste generation and encouraging the re-use of products. On the other hand, the restraining role of the moratorium could decrease over time due to the management capacity constraints, allowing the expansion of landfills or the creation of new disposal facilities, the effects of which on the State policies for waste reduction are yet to be analyzed.

In terms of technology, incineration will continue to play an important role by improving the energy generation rates and by considering the implementation of co-generation systems. As disposal constraints become more evident in the future, policies incorporating a ban on certain types of solid waste will have the effect of promoting the development and implementation of other waste-to-energy technologies. Thus, new schemes could be centred on household and commercial organic waste fractions in order to produce energy and compost as by-product. Other possible scenarios consider the use of solid waste in the co-firing process in areas such as the steel and cement industries.

As for socio-economic drivers, public awareness and the role of society in the decision-making process could further promote regulations and policies aimed at tackling the environmental problems associated with waste management activities, for example, the case of air pollution from the incineration facilities (e.g. dioxin air emissions), transportation of waste and poor landfill practices. Moreover, aspects such as demographic changes and society consumption patterns are already playing a relevant role in the development of waste management.

### Drivers for Yokohama city MSW system

The city of Yokohama is located next to Tokyo and comprises a part of a greater Kanto region, the largest urban agglomeration in the world. The population of Yokohama alone is increasing slowly and exceeded 3.6 million in 2006. Projec-

tions indicate that it would stabilize at 3.6–3.7 million in 2015 and experience a slight decrease to 3.5 million in 2020 (EPB 2004a). Until 2000, the amount of MSW increased steadily along with the population. It grew from 0.96 million in 1980 to 1.65 million tonnes in 2000 (UMPB 2006). In detail, waste from commercial sources was identified as a particular problem since the amount of the household waste had not shown any increases since 1997. Recycling accounts for about 67,000 tonnes representing 4.2% of the total municipal solid waste, about 1500 tonnes are incinerated representing 95.4% of the solid waste generated which is disposed of into landfills accounting for about 285,000 tonnes. As landfill space is one of the major concerns for solid waste management, the city has gradually increased the contribution of recyclables as part of a source separation scheme. For instance, separate collection was started for cans and glass bottles in 1993 (fully implemented in 1995), for small metals in 1997 and for PET bottles in 1999 (fully implemented in 2002). Late in 2005, the city launched the skim for source separation of all plastics, papers and textiles (EPB 2005a).

### Legislation and regulation drivers

#### Before 1990 and 1990–2005

Before the 1990s, rapid economic growth made legislation on waste management focus on end-of-pipe technologies, such as the introduction of guidelines and technical notes for landfills. However, the exhaustion of landfill capacity and the increasing environmental burden from municipal and industrial waste called for a radical shift in national waste management strategy. From 1990 onwards, ‘cleaning up the past environmental burdens’, ‘responsibility of polluters’, ‘extended producer responsibility’ and the ‘establishment of recycling oriented society’ have been set as baseline philosophies of the national waste management policy (MOE 2005c). At the municipal level, the latter two aspects have been seen as particularly important since they had a large influence on Yokohama’s solid waste management by introducing the concepts of solid waste recycling, reduction and re-utilization. In 1991, the first resource recycling promotion law (later amended to law for the promotion of utilization of recyclable resource in 2001) came into effect promoting the ‘3R’ activities. Meanwhile, the waste management policy included waste reduction and recycling. As for the responsibility of manufacturers and the promotion of recycling by citizens, the first containers and packaging recycling law was passed in 1995. Afterwards, the amended containers and packaging recycling law (2000), home appliance recycling law (2001), food recycling law (2001), construction material recycling law (2002) and end-of-life vehicle recycling law (2005) were promoted accordingly (MOE 2005c). Later, the international trade of waste as a resource was incorporated into waste management law. As part of the promotion of utilization of recyclable resource law, municipal governments were required to set an action plan for establishing a recycle-oriented society. In the case of the city of Yokohama, biomass recycling was covered by the Biomass Nippon Action Plan in 2002.

### 2005–2025 and future

In 2004, the national government advocated a commitment to promote a philosophy of the three ‘R’s in the G8 summit and the initiative was officially started in 2005. It stressed the aspiration to promote waste-related technologies and multiple stakeholder participation. This may result in strengthening laws and regulations focused on ‘extended producer responsibility’ and ‘establishment of a recycling oriented society’.

As yet, the two landfill sites are expected to reach their capacity within 10 years at current rates and a close co-ordination with these two laws must be a top priority (EPB 2005a). As a result, local government first launched the ‘G30 campaign’ that endorses reduction in the amount of waste by 30% by 2010 from the baseline year of 2001; second, the city took the step of introducing 10 categories and 15 different goods in the separation of household waste since 2005. In the coming years, future policies may focus on tackling the upper stream of solid waste management hierarchy in order to support the actual the ‘3R’-related policies and the development of alternative treatments.

### Regional and international drivers

#### Before 1990 and 1990–2005

In recent years, there has been a boost in the export of recycled materials from the country. The amount of exported waste increased 10-fold from 1990 to 2004 (MOE 2005b). In particular, the export of paper and plastic waste increased from 21.900 to 3108.5 thousand tonnes and from 41.4 to 1053.2 thousand tonnes from 1990 to 2005, respectively (Figures 5 and 6; MOF 2006). The same trend was observed for non-ferrous metals (*e.g.* aluminium and copper).

Nevertheless, this phenomenon introduced other problems at the municipal level. It was found that an imbalance of cost and demand between domestic and international markets has encouraged more and more collected PET bottles to be exported to other Asian countries (*e.g.* China) (MOE 2005b). Thus, Japanese PET recycling companies have failed to secure the enough material to sustain their businesses.

### 2005–2025 and future

In coming years, similar trends are projected for the export of recyclable materials, as the added value for plastic wastes like PET bottles will have a large demand from other Asian countries and the domestic economy. According to Li and Yasuda (2004), the cost of a series of recycling materials such as PET bottles, glass bottles, steel and aluminium cans in Yokohama were remarkably reduced from 1995 to 2002; this, in turn, may increase the competition between international and national demand for recyclable materials and other elements from the solid waste stream.

Although local government policy towards the export of recyclable materials is still unclear, economic globalization may sustain such trading in the future. In 2005, the Kyoto Protocol came into force and now the government has a legally binding objective to reduce CO<sub>2</sub> emissions by 6% against the baseline level of 1990 by the end of 2012. The national action

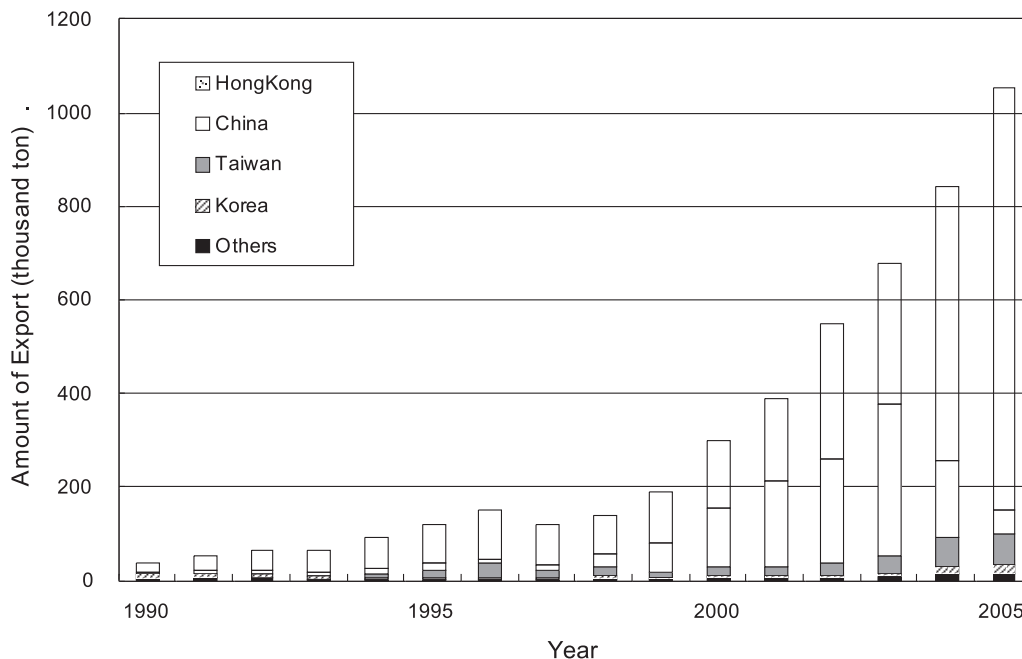


Fig. 5: Amount of waste plastic exported from Japan during 1990–2005.

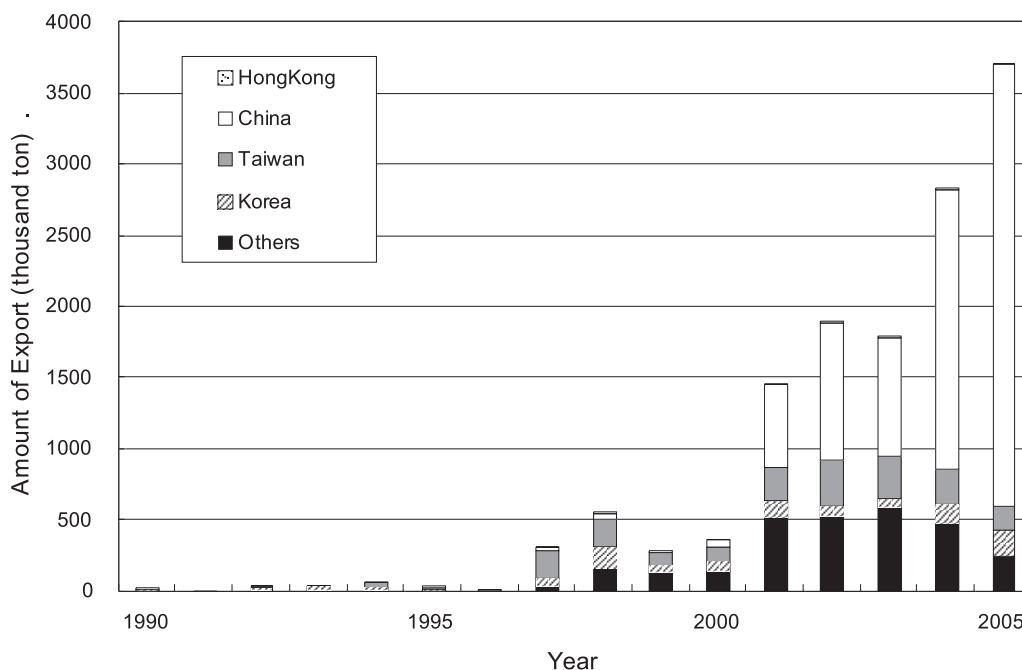


Fig. 6: Amount of waste paper exported from Japan during 1990–2005.

plan for the Kyoto Protocol clearly indicated reduction of CO<sub>2</sub> emissions from the waste incineration process and called for active participation of municipal governments (MOE 2005a).

**Technology development and institutional drivers**

**Before 1990 and 1990–2005**

Over the years, incineration was the main treatment process for solid waste disposal. As landfills played an important role,

technologies for waste management were mainly focused on improving the conditions of final disposal sites. However, in the early 1990s, technological improvement in the incineration process was the central interest of government. This shift was triggered by concerns that a source of carcinogenic pollutants (*i.e.* dioxin) came from the incomplete combustion of plastic waste. Since then, a number of drawbacks inherent in the incineration processes were overcome by technological developments.

### 2005–2025 and future

As advancements in technology offer other options to reduce the environmental burdens related to solid waste while allowing the recovery of different resources, thermal recycling in Tokyo (the adjacent municipality) is an example of a system capable of safely incinerating plastics from industrial sources and the plastics from municipal solid waste. Moreover, most of the waste incineration plants in Tokyo have already doubled the traditional energy recovery efficiency (Tokyo Metropolitan Government, personal communication). The primary advantage of these technologies is that there is little need for source separation when handling the waste. For material recycling, a range of technologies, such as plastic-to-plastic, recycled paper, pellet, animal feed manufacturing have also been developed. Other technologies include transforming the materials to fuel, such as biogasification, esterification, gasification, carbonisation and so forth.

Some of these technologies are expected to become technically and economically feasible options. According to the survey on municipal governments (Organization 2004), opinions on whether to incinerate the plastic or not were varied, and has not been answered by national government either. Since Yokohama decided to increase separation of household waste, it might be less likely to follow single thermal recycling as did Tokyo. Yokohama has the largest biogasification plant, which recovers energy from sewage sludge. This might offer a possible technological option to utilize organic waste from the MSW. The availability of various technological options is expected to provide an opportunity to facilitate a tailor-made solution for each locality.

### Socio-economic drivers

#### Before 1990 and 1990–2005

Socio-economic drivers are probably the most important factor for Yokohama and other municipalities in Japan to for-

mulate MSW management strategies. In particular, population can be seen as one of the most influential parameters as it is directly associated with the amount of MSW produced. Until 2005, the population of Yokohama has steadily increased, although the amount of household waste to be treated has not changed or decreased since 1994 (Figure 7).

This seems to correspond with the fact that Yokohama started to collect cans and bottles as part of the separation scheme from 1995. For the quality of the solid waste, Figure 8 shows household solid waste composition for the city of Yokohama from 1990 to 2004 where a steady decrease in cans and bottles over the years and similarly increase in paper, plastics and food waste were observed. Regression analysis for these three types of solid waste between 1970 and 2004 also reveal a similar behaviour for household solid waste composition (Figure 9) (Takanashi *et al.* 1998). However, as population consumption patterns change, it might also be necessary to consider the scenario where an increase in the use of plastics as packaging material in recent years might cancel out the reduction induced by the separate collection of PET bottles and other plastic materials.

As another important driver, environmental consciousness towards solid waste management has increased over the years. In the case of Japanese cities, the positioning and construction of new solid waste related facilities has turned into a challenge – not only due to limited space but also for social acceptance and environmental and economic sound management (Rahardyan *et al.* 2004). However as highlighted by Suzuki *et al.* (2004), this environmental consciousness does not mean an increase in Japanese environmental-friendly behaviour.

#### 2005–2025 and future

To estimate the future amount of municipal solid waste in Yokohama, multiple regression analysis was carried out by

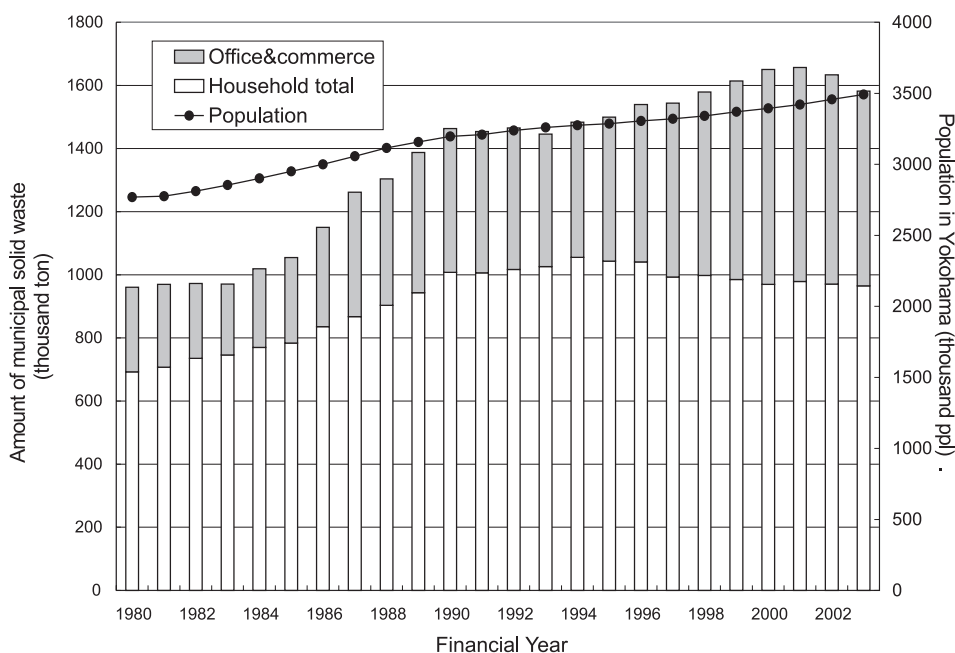


Fig. 7: Amount of municipal solid waste and population in Yokohama (1980–2003). Created from City of Yokohama (2006).

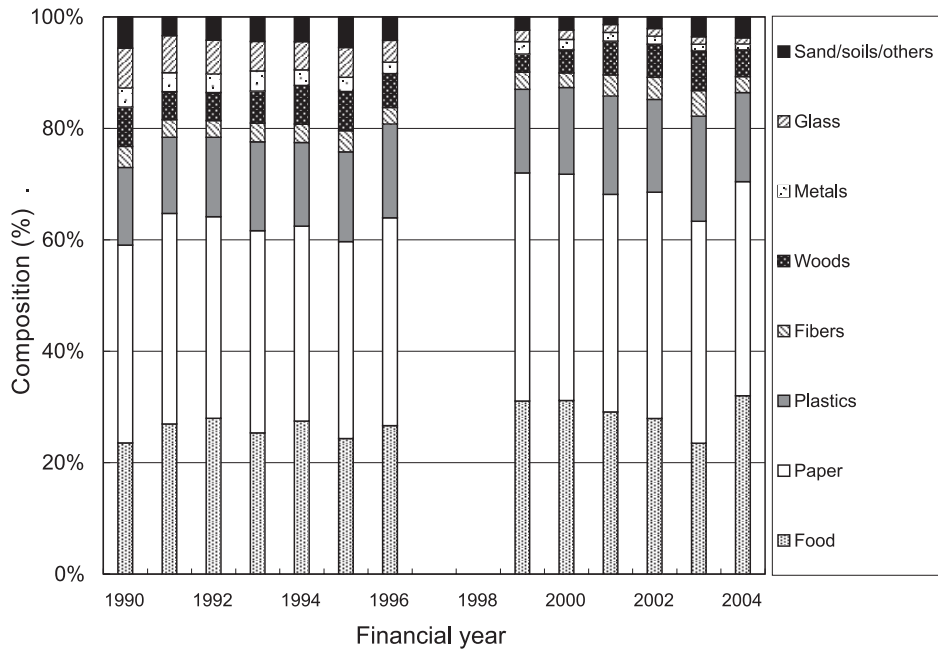


Fig. 8: Composition of household waste in Yokohama during 1990–2004. Created from Takahashi et al. (1998) and City of Yokohama (2004).

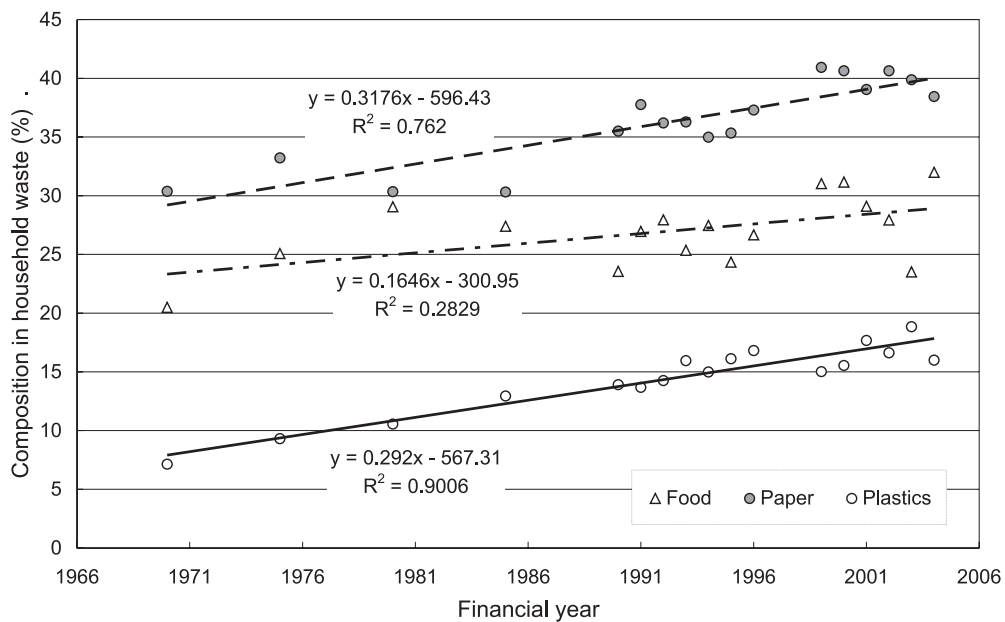


Fig. 9: Composition of food, paper and plastic in municipal solid waste during 1970–2004. Created from Takahashi et al. (1998) and City of Yokohama (2004).

using three categories of population, namely below ‘14 years old’, ‘between 15 to 64 years old’ and ‘65 years old and over’ as explanatory variables. It was shown that the multiregression prediction had a good correlation with actual data ( $r^2 = 0.98$ ) (Figure 10). By extending the prediction by means of projected population in Yokohama (broken line in Figure 10) (EPB 2004b), the amount of household waste generated will be 834.8 thousand tonne in 2010 and 703.5 thousand tonnes in 2020. This corresponds to a 14.7% and 28.1% reduction from the baseline year of 2001, respectively.

Caution is needed for such interpretation but suggests that future MSW management can be influenced significantly. In terms of composition, a recently installed increasing source separation scheme in Yokohama resulted in remarkable changes by reducing the overall amount (30% less), its composition (high organic content) and water content (1.5 times more) of the waste (EPB 2005b).

Public awareness in waste management is rising steadily. According to a survey of general public perception towards daily life in Yokohama in 2005, the percentage of people who

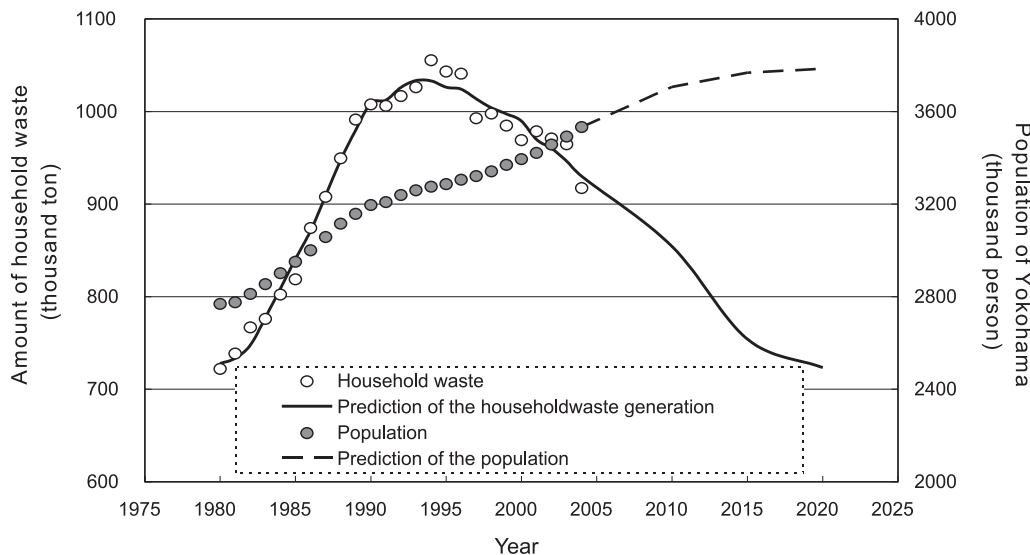


Fig. 10: Prediction of population and amount of household waste generated in Yokohama until 2020. Created from City of Yokohama (2006).

included 'environmental problem' in their top three anxieties in daily life rose from 6.5% in 1980 to 13.4% in 2005 (EPB 2005a). Another public survey revealed that 74.5% of people answered 'reducing and recycling the waste' as their environmental problem of interest. Furthermore, 'tackling illegal dumping of the waste' and 'promoting reduction and recycling of the waste' were selected as second and third top priority issues of environmental management out of 27 issues in total. This was followed by 'addressing the climate change and CO<sub>2</sub> emission' (EPB 2005c).

#### Shift over the two time periods

During the past 10 years, efforts for waste reduction and recycling have greatly increased throughout Japan, based on the '3R's concept. In Yokohama, the application of a new separation scheme (which includes 10 separations instead of the three actual categories) and the G30 policy (for reducing the amount of waste generated by 30% in coming years) will play an important role in shaping the future management system.

The changes in the MSW separation scheme might influence the use of incineration as the main treatment for solid waste to include also other technologies, such as biogasification (with actual examples of sewage sludge biogasification plants) and thermal recycling. Obligations for GHG reduction under the Kyoto Protocol at the national level could promote and improve recycling schemes while also broadening the technological alternatives for household waste treatment (e.g. co-generation, district heating). Nevertheless, caution is needed when analyzing the future development of Yokohama MSW management since the increasing demand of solid waste from other Asian countries could trigger a shift in solid waste composition.

In terms of demographic changes, the slow decrease in the population as well as an ageing social structure in most Japanese cities will affect quantity and quality of the solid waste

with implications on MSW management in the near future, compared to past trends of positive solid waste generation (Figure 10). The rising public expectation can be seen as another socio-economic driver, whose influence will increase in the future by being an essential part in the design of separation and treatment alternatives (e.g. recycling, source separation of solid waste). The shift in the importance of these drivers should be carefully incorporated into the future MSW management in Yokohama (Figure 11).

#### Discussion

The analysis of both cases of study based on the analytical framework has identified changes in the role of some drivers influencing solid waste management. In different situations, the role of a particular driver or category has increased, maintained or decreased compared to previous years. Furthermore, the analysis shows how the reasons behind the development of some drivers have been different. In Boston, the RCRA regulation which provided the initial guidelines for solid waste management throughout the country was, in part, developed as a response to public health and environment-pollution episodes. As for the city of Yokohama, the rapid economic growth and consequent increase in the amount of waste drove legislation to be focused on improving the incineration and landfill practices to couple with the disposal constraints at that time, to later move to reduce the environmental burdens and to support a recycling-oriented society policy.

At present, an emerging driver influencing solid waste flow and local management systems is the movement of solid waste as a recyclable resource between economies mostly due to the demand for resources by the growing Asian economies (IDE 2005). In both cases of study, the trade in recyclable resources has increased over the past years; for Japan, the amount of exported recyclable waste has expanded over 10-fold since 1990 (EPB 2005b). Moreover, solid waste move-

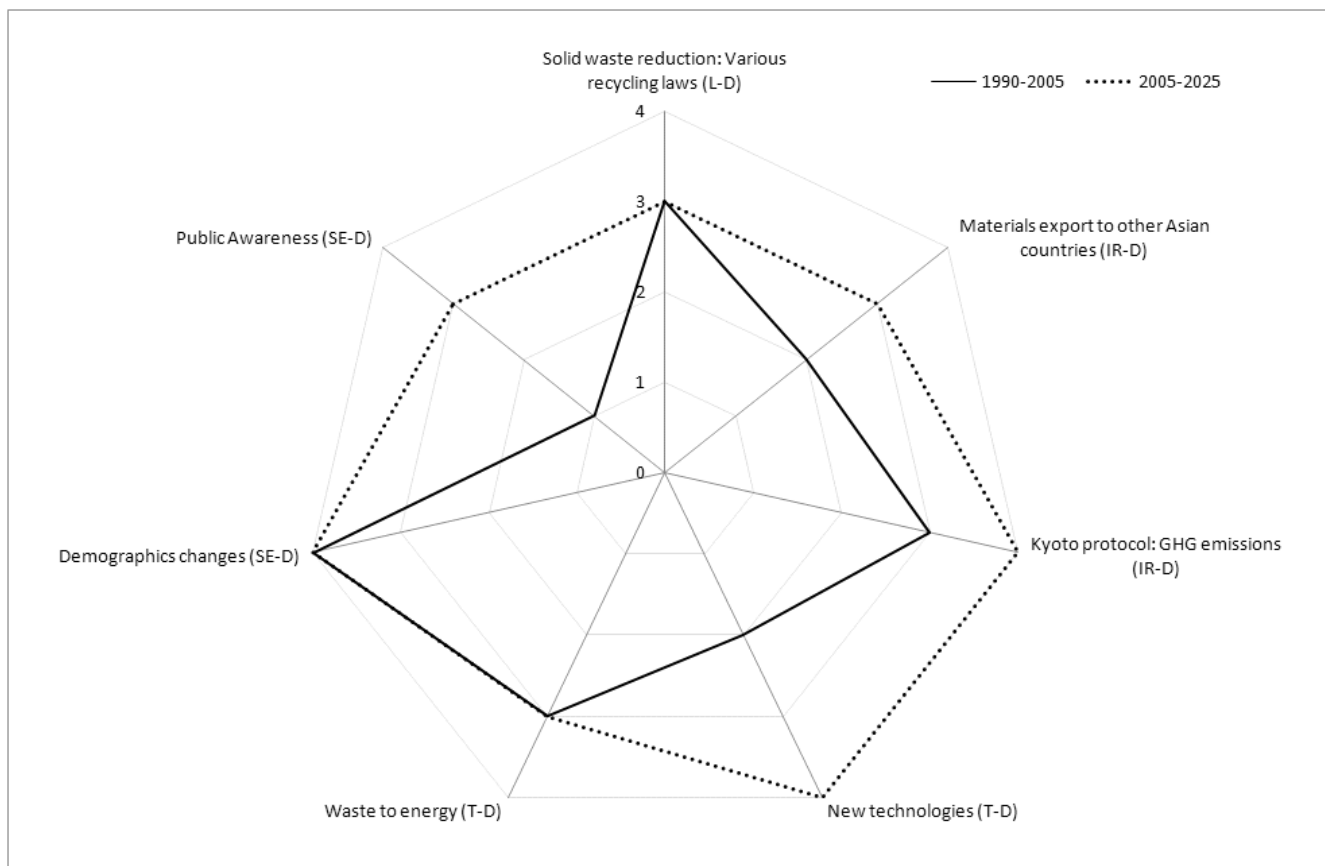


Fig. 11: Radial chart showing changes in importance for Yokohama drivers over two time periods. L-D, legislation and regulation drivers; T-D, technological and development and institutional drivers; IR-D, regional and international drivers; SE-D, socio-economic drivers.

ment can be also described in the Boston case as the treatment and disposal of municipal solid waste in the surrounding states due to disposal constraints within the State boundaries.

Innovation in technology is driven in waste management by a series of aspects ranging from policies involving reduction targets for local pollution to international agreements for GHG emissions. Over the years, the management of solid waste has gradually moved from the use of end-of-pipe technologies as landfills to consider a sound material cycle approach by adopting recycling and waste-to-energy schemes. The improvement in energy efficiency rates of waste incineration plants and the implementation of new approaches (such as biogasification, landfill gas capture and thermal treatment) are examples of the future direction of technology development. As described by Gohlke (2007), there is a large potential for innovations in terms of energy efficiency, ash quality and cost efficiency in the waste-to-energy industry.

As part of socio-economic drivers, it is projected that the population in Yokohama would peak around 2015 while Boston (State) population is expected to increase steadily over the next 30 years providing valuable information for managers. Moreover, the relevance of public awareness and participation will transcend in the near future in response to pollution associated with the treatment and disposal of solid

waste. Nowadays, public environmental consciousness is also playing an important role in the design and implementation of present separation and recycling schemes while future trends for population growth and solid waste composition will play a key role in solid waste management.

#### Differences in importance of municipal solid waste drivers

Below, we explore how the importance of these categories and underlying drivers may change under certain scenarios. As a premise, we assume a certain level of interdependence and/or influence among the several municipal solid waste drivers. In order to sustain this analysis, we first consider a possible scenario where the importance of a driver declines in favour of others; second, we consider the possibility of a driver becoming more important to start influencing the role of other drivers.

In the first scenario, a future decrease in the amount of solid waste being disposed to other states may provide the conditions for future regulation drivers to be oriented towards '3R' policies to improve the State solid waste management capacity (Boston case study). Indirectly, technology development drivers may play a stronger role by providing the means to reduce the amount of solid waste being disposed of by new recycling schemes, application of other treatment technologies (e.g. biomass composting and biogasification) and the improve-



ment of actual incineration techniques. On the other hand, a lowering in the regulation restricting new disposal sites may reduce pressure on the MSW disposal system, leading to a decrease in the efforts towards waste reduction and recycling while increasing the application of regulations and development of technologies focused on reducing impacts related to landfills.

Under the second scenario, an increase in public awareness towards environmental loadings from solid waste treatment and disposal could lead to the implementation of stronger policies and regulations focused on reducing the amount of solid waste disposed on landfills through wider recycling and treatment options. In the case of the Yokohama study, international agreements for GHG reduction targets is influencing the application of policies to promote a recycling-oriented society while strengthening the role of drivers such as legislation and regulations to reach this objective. Meanwhile, these conditions promote the application and development of technologies such as methane gas collection and biogasification to reduce the amount of GHG emissions.

### Concluding remarks

This paper has discussed a driven analytical framework to support the analysis of municipal solid waste systems. The proposed framework presents an approach to analyze the development of solid waste management over the years based on four driver categories while focusing on how the role or importance of these drivers could change in the near future. The application of this framework to analyze MSW management for the cities of Boston and Yokohama within two time periods lead us to believe that the role or importance of a category (or, in other words, of a driver) varies in each particular case. Although both solid waste systems share some similarities, they involve a different set of drivers and circumstances which influenced the development of each particular management. As for the first time period (before 1990 and 1990–2005), solid waste management capacity for both cases was under stress due to different reasons. In the case of Boston, the moratorium on new treatment and disposal facilities played an important role, while a demographic change was a key driver for the city of Yokohama.

However, the analysis of both solid waste scenarios for the second time period (2005–2025 and future) lead us to believe that other drivers may also play a relevant role. Socio-economic drivers will continue to have an important place in solid waste management, for example, a demographic and social shift including city life-styles could be a future constraint and opportunity. An increasing stakeholder's participation and citizen's acceptance to bear the environmental cost might stimulate some technologies, making them preferred options. Moreover, new technologies for waste treatment and recycling together with the rising interest in solid waste as a recyclable resource by other economies will have an important role as drivers. However, additional research is

needed to evaluate the impact of the new global economic scenario considering the decrease of recyclable waste by developing economies (e.g. China and India). Under these conditions, several questions may arise. For example, how MSW management for the cities of Boston and Yokohama may react to this inflow of waste or what is the reaction of local recycling companies to this inflow of waste? Therefore, emphasis should be given to recognize the changes in drivers' importance over time in order to define future management policies.

As part of the limitations of this research, we acknowledge that other studies may analyze a solid waste system considering a different range of drivers. Because the circumstances behind a city solid waste system are diverse, other driver categories may be applicable. Thus, we recommend the selection and description of the categories to be made in collaboration with experts and validated by the different stakeholder groups according to the scope of the study.

Since the importance or relevance of a driver was defined based on the authors' experience of solid waste management and the characteristics of the case of study, we believe that the application of methods such as AHP, ELECTRE or PROMETHEE together with this research will produce other results where the integration of several experts or interested parties will be crucial. For example, Hokkanen and Salminen (1997) have employed the outranking method ELECTRE in the context of choosing a solid waste management plan for a city in Finland based on the preferences of several decision makers. Contreras *et al.* (2008) applied AHP to integrate stakeholder preferences into the evaluation of different MSW alternatives. Furthermore, understanding how the importance of a driver might hinder or trigger the influence of other drivers could lead to new important findings.

Despite the limitations of the method, we consider a specific advantage of the analytical framework to allow the evaluation of drivers among two time periods based on a set of categories. For example, the analysis for the two cases of study through this framework highlighted technological options, international trade opportunities and socio-economic shifts as key drivers for future solid waste management. Furthermore, managers and practitioners will be faced with the challenge of considering, as part of their analysis, an integrated waste management system, drawing the most suitable series of waste collection scheme, treatment technologies and disposal options, and how the importance or role of these drivers could change over time.

### Acknowledgements

This research was made possible thanks to the Massachusetts Department of Environmental Protection and Yokohama Department of Environment who provided information and replied to our questions. The authors would also like to thank the Center for Excellence Program on Sustainability (COE) at the University of Tokyo for their financial support.

## References

- Altschuler, G.C. (2005) Waste land: Elizabeth Royte lifts the lid on the ever-expanding world of debris and its disposal. *The Boston Globe*, Boston, MA.
- Binder, C.R. & Mosler, H.-J. (2007) Waste-resource flows of short-lived goods in households of Santiago De Cuba. *Resources, Conservation and Recycling*, **51**, 265–283.
- Bureau, U.S.C. (U.S. Census Bureau) (2006) *2004 Population Estimates*. <<http://factfinder.census.gov>> [accessed November 2007].
- Capone, L. (2000) Overall cap urged on toxic emissions. *The Boston Globe*, Boston, MA.
- Capone, L. (2003) Grant boosts activist targeting firm. *The Boston Globe*, Boston, MA.
- Coggins, P.C. (1994) Who is the recycler? *Journal of Waste Management and Resource Recovery*, **1**, 69–75.
- Contreras, F., Hanaki, K., Aramaki, T. & Connors, S. (2008) Application of analytical hierarchy process to analyze stakeholders preferences for municipal solid waste management plans, Boston, USA. *Resources, Conservation and Recycling*, **52**, 979–991.
- DEP (Department of Environmental Protection). (2000) *Beyond 2000 Solid Waste Master Plan: A Policy Framework*. Executive Office of Environmental Affairs, Commonwealth of Massachusetts.
- DEP (Department of Environmental Protection). (2004) *Third Annual Progress Report on the Beyond 2000 Solid Waste Master Plan*. Executive Office of Environmental Affairs, Commonwealth of Massachusetts.
- DEP (Department of Environmental Protection). (2005) *Solid Waste Master Plan: 2005 Revision, Public Hearing Draft*. Executive Office of Environmental Affairs, Commonwealth of Massachusetts.
- DEP (Department of Environmental Protection). (2006) *Solid Waste Mater Plan: 2006 Revision*. Executive Office of Environmental Affairs, Commonwealth of Massachusetts.
- Desmond, M. (2006) Municipal solid waste management in Ireland: assessing for sustainability. *Irish Geography*, **39**, 22–33.
- EEA (European Agency of Environment). (2004) *Consumption Drivers*. <<http://epaedia.eea.europa.eu/page.php?pid=409>> [accessed 9 January 2008].
- EIA (Energy Information Administration). (2005) *Renewable Electric Power Sector Net Generation by Energy Source and State*. Department of Energy U.S. <[http://www.eia.doe.gov/cneaf/solar/renewables/page/rea\\_data/table18.html](http://www.eia.doe.gov/cneaf/solar/renewables/page/rea_data/table18.html)>.
- EPA (Environmental Protection Agency U.S.). (2003) *Waste and Materials Management in the Year 2020*. EPA530-R-02-009.
- EPA (Environmental Protection Agency U.S.). (2006) *Laws and Regulation, Waste Section*. <<http://www.epa.gov/osw/laws-reg.htm>> [accessed 10 January 2006].
- EPB (Environmental Planning Bureau Yokohama City). (2004a) *Environmental Report 2004* (in Japanese). Yokohama.
- EPB (Environmental Planning Bureau Yokohama City). (2004b) *Future Population Projection in Yokohama* (in Japanese). Yokohama <<http://www.city.yokohama.jp/me/keiei/seisaku/jinkou/>>.
- EPB (Environmental Planning Bureau Yokohama City). (2005a) *Citizen's Survey in Yokohama 2005*. Yokohama <<http://www.city.yokohama.jp/me/keiei/seisaku/chousa/ishiki/17/index.html>>.
- EPB (Environmental Planning Bureau Yokohama City). (2005b) *Press Release 'Broaden the Scope of Source Separation Results in Little but Heavy Household Waste'*. Yokohama <[www.city.yokohama.jp/me/pcpb/new/press/pre050630.pdf](http://www.city.yokohama.jp/me/pcpb/new/press/pre050630.pdf)>.
- EPB (Environmental Planning Bureau Yokohama City). (2005c) *Survey on Yokohama Environmental Management Plan*. Yokohama <<http://www.city.yokohama.jp/me/keiei/seisaku/chousa/ishiki/17/index.html>>.
- Ericsson, K., Nilsson, L. (2004) International biofuel trade – a study of the Swedish import. *Biomass & Bioenergy*, **26**, 205–220.
- Fallon, M., Dwayne, B. & Massachusetts, A. (Bureau of Forestry Department of environmental Management). (2002) *The Woody Biomass Supply in Massachusetts: A Literature Based Estimate*. Massachusetts, Commonwealth of Massachusetts.
- Garrick, L. (2004) A historical context of municipal solid waste management in the United States. *Waste Management & Research*, **22**, 306–322.
- Gohlke, O. & Martin, J. (2007) Drivers for innovation in waste-to-energy technology. *Waste Management & Research*, **25**, 214–219.
- Goldstein, J., 2003. *Waste Reduction Program Assessment and Analysis for Massachusetts*. Tellus Institute, Boston, MA, USA.
- Graham, J. (2003). *Inventory of Anthropogenic Mercury Emissions in the Northeast*, NESCAUM.
- Greve, F. (2005) *U.S. Paper Recycling Reaches a Record High*. Knight Ridder Washington Bureau.
- Hammel, S., McCarthy, G., Tennis, A. & Friedman, E. (2004) *Massachusetts Climate Protection Plan*. The Commonwealth of Massachusetts.
- Hockett, D., Loberf, D. & Pilgrim, K. (1995) Determinants of per capita municipal solid waste generation in the South-Eastern United States. *Environmental Management*, **45**, 205–217.
- Hokkanen, J. & Salminen, P. (1997) Choosing a solid waste management system using multicriteria decision analysis. *European Journal of Operational Research*, **98**, 19–37.
- Institute of Developing Economies. (2005) *International Trade of Recyclable Resources in Asia*. Chiba (29).
- Lajoie, K. (1998) *Close the Claremont Incinerator*. *The Boston Globe*. Boston, MA.
- Li, S. & Yasuda, Y. (2004) Analysis and assessment of drinking bottle recycling policy in Yokohama (in Japanese). Proceedings of the 15th Annual Meeting of Japan Society of Waste Management Experts.
- MAPC (Boston Metropolitan Area Planning Council). (2006) *Population Totals by Municipality*. <<http://www.mapc.org/>>.
- McDougall, F., While, P., Franke, M. & Hindle, F. (2002) *Integrated Solid Waste Management: A Life Cycle Inventory*. Oxford, UK: Blackwell.
- Melosi, M. (2000) *The Sanitary City*. Baltimore, MD: Johns Hopkins University Press.
- Mendes, M.R. (2003) *A Comparison of the Environmental Impacts of Municipal Solid Waste Management Options by Life Cycle Assessment*. *Urban Engineering*. Tokyo: The University of Tokyo.
- MOE (Ministry of the Environment Japan). (2005a) *Action Plan for Fulfilling the Target of the Kyoto Protocol* (in Japanese). <[http://www.env.go.jp/press/file\\_view.php?serial=6699&hou\\_id=5937](http://www.env.go.jp/press/file_view.php?serial=6699&hou_id=5937)>.
- MOE (Ministry of the Environment Japan). (2005b) *Trend of international resource circulation*. Waste and Recycling Policy Council, 21 December (in Japanese). <<http://www.env.go.jp/council/03haiki/y0310-03.html>>.
- MOE (Ministry of Environment Japan). (2005c) *White Paper on the Environment, Japan 2005*. <<http://www.env.go.jp/policy/hakusyo/hakusyo.php?kid=222>>.
- MOF (Ministry of Finance Japan). (2006) *Trade Statistics of Japan*. <<http://www.customs.go.jp/toukei/info/index.htm>>.
- Montville, J.B. (2001) *Refuse Truck Photo Archive*. St Paul, MN: MJB Publisher.
- National Research Institute of China. (2003) *Municipal Solid Waste Management in China*.
- Nielsen, S.G. (2003). *Liberalization of Waste Incineration – a Scenario Study of Future Treatment Prices and Amounts of Waste Designated for Combustion in the Region of Öresund* (in Danish). Institut for Miljø, Teknologi og Samfund. Denmark, Roskilde Universitetscenter.
- Olofsson, M., Sahlin, J., Ekvall, T. & Sundberg, J. (2005) Driving forces for import of waste for energy recovery in Sweden. *Waste Management and Research*, **23**, 3–12.
- Joint Association of Waste Related Organization, Japan. (2004) *Questionnaire Survey on Municipal Solid Waste Management Towards Creating the Recycle Oriented Society* (in Japanese).
- Rahardyan, B., Matsutoa, T., Kakutab, Y. & Tanakaa, N. (2004) Resident's concerns and attitudes towards solid waste management facilities. *Waste Management*, **24**, 437–451.
- Rasmussen, C. & Reimann, P. (2004) *Recovery of Combustible Waste. Welfare Economic Analysis of Co-Combustion at the Cement Production of Aalborg Portland a/S* (in Danish). Copenhagen, Denmark: Institute for Miljøvurdering.
- Rudden, P.J. (2007) Policy drivers and the planning and implementation of integrated waste management in Ireland using the regional approach. *Waste Management Research*, **25**, 270–275.
- Schultz, P.W., Oskamp, S. & Mainieri, T. (1995) Who recycles and when? A review of personal and situational factors. *Journal of Environmental Psychology*, **15**, 105–121.

- Stewart, B., Gilg, A. & Ford, N. (2001) Differences between household waste reduction, reuse and recycling behavior: a study of reported behaviors, intentions and explanatory variables. *Environmental & Waste Management*, **4**, 69–81.
- Suzuki, K., Futagami, T., Ogura, S., Hara, M., Okawa, T. & Yasui, I. (2004) Change in environmental consciousness and behavior led by information. 6th International Conference on EcoBalance, Tsukuba, Japan.
- Takanashi, T., Mikami, Y. & Teraoka, Y. (1998) Trend of waste composition in Yokohama (in Japanese). *Journal of Japan Waste Management Association*, **51**, 140–145.
- Tchobanoglous, G., Thiesen, H. & Vigil, S. (1992) *Integrated Solid Waste Management*. California: McGraw-Hill.
- Tchobanoglous, G., Thiesen, H. & Eliassen, R. (1978) *Solid Waste: Engineering Principles and Management Issues*. New York: McGraw-Hill.
- Terazono, A., Yoshida, A., Yang, J., Moriguchi, Y. & Sakai, S. (2004) Material cycles in Asia: especially the recycling loop between Japan and China. *Journal of Material Cycles and Waste Management*, **6**, 82–96.
- Tiarr, J.A. (1988) *Sewerage and the Development of Networked City in the United States, 1850–1930*. Philadelphia, PA: Temple University Press.
- Tiarr, J.A. (1996) *The Search for the Ultimate Sink*. Akron, OH: University of Akron.
- Tonglet, M., Phillips, P., Bates, M. (2004) Determining the drivers for householder pro-environmental behavior: waste minimization compared to recycling. *Resources, Conservation and Recycling*, **42**, 27–48.
- UMPB (Urban Management and Planning Bureau). (2006) *Statistical Portal Site of Yokohama*. <<http://www.city.yokohama.jp/me/stat/>>.
- Visvanathan, C. & Trankler, J. (2004) *Municipal Solid Waste Management in Asia: A Comparative Analysis*. Klong Luang, Thailand: Environmental Engineering and Management, School of Environment, Resources and Development, Asian Institute of Technology.
- White, P., Franke, M. & Hindle, P. (1999) *Integrated Solid Waste Management*. Gaithersburg, MD: Aspen Publications.
- Williams, J.F. (2004) *Waste to Energy 25 Years Later: Technology with a Past, Present, and Future*. MSW Management 14.
- Wilson, D.C. (2007) Development drivers for waste management. *Waste Management & Research*, **25**, 198–207.
- Woolridge, A., Morrissey, A. & Phillip, P.S. (2005) The development of strategic and tactical tools, using systems analysis, for waste management in large complex organizations: a case study in United Kingdom healthcare waste. *Resources, Conservation and Recycling*, **44**, 115–137.