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ORIGINAL ARTICLE

Economic growth and selection of municipal waste treatment options in Bangkok

Shigefumi Okumura[1] · Tomohiro Tasaki[2] · Yuichi Moriguchi[3] · Wassana Jangprajak[4]

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Abstract A reasonable selection of waste treatment options is indispensable to address challenges in waste management. Introduction of incineration plants for municipal waste in Bangkok had been considered in the past, but each time it was dismissed. In 2013, however, the Bangkok Metropolitan Administration (BMA) decided to introduce an incinerator facility with electricity generation. This study examined how changes in socio-economic factors resulting from economic growth affected the BMA's decision. First, we conducted interviews of key relevant stakeholders (policymakers and other experts) to determine what kinds of changes in socio-economic factors affected their decision. Then, for interpretation and confirmation of the results from interview, we quantitatively estimated changes in environmental factors (e.g., greenhouse gas emissions), financial factors (e.g., construction and operating costs), and social factors (e.g., employment) in 1990, 2000, and 2012. Based on the result of interview and quantitative analysis, we illustrated the complicated structure of the mechanism of how economic growth affected the selection of waste treatment options in Bangkok, particularly those that led to the selection of the incineration. In addition to local conditions, global economic also affected the waste treatment policy in Bangkok even though waste management is usually thought of as a local issue.

Keywords Waste management · Economic growth · Developing country · Incineration · Composting

Introduction

Waste generation has increased with economic growth in Asian countries, and waste management has become an increasingly serious issue. Experts and government officials in Asia have highlighted various challenges such as scarcity of landfill sites, illegal dumping, and health problems affiliated with uncollected waste (see, e.g., Agamuthu et al. [1]). To address these challenges, appropriate waste management, particularly waste treatment, is indispensable.

The selection of waste treatment options differs by country because each country has different environmental, economic, social, and other conditions. Many existing studies (e.g., [2–4]), have quantitatively analyzed the advantages and disadvantages of different waste treatment options, but they have not considered change of the advantages and disadvantages caused by the change of a country's environmental, economic, and social conditions. Regarding historical trends in waste treatment options, Bertolini [5] observed positive relationships between gross national income (GNI) per capita and incineration rate among countries at different economic levels in 2000. Mazzanti and Zoboli [6] showed a positive relationship between household consumption per capita and incineration rate and a negative relationship between

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✉ Shigefumi Okumura
okumura@kanies.k.u-tokyo.ac.jp

[1] Department of Environment Systems, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa, Chiba 277-8563, Japan

[2] Center for Material Cycles and Waste Management Research, National Institute for Environmental Studies, Tsukuba, Japan

[3] Department of Urban Engineering, The University of Tokyo, Tokyo, Japan

[4] Faculty of Environment and Resource Studies, Mahidol University, Salaya, Nakorn Pathom, Thailand

household consumption per capita and landfill rate in EU member countries. Similarly, Okumura et al. [7] indicated a positive correlation between gross domestic product (GDP) per capita and incineration rate at the country level in Japan, Korea, and China. Okumura et al. [7] also pointed out that experts and government officials in Southeast and East Asian countries had different preferences on the balance among environmental, economic, and social factors according to GDP per capita in these countries [e.g., experts in upper middle-income countries (GDP per capita is USD 4036–12,475) regarded social acceptance to be more important than those in the other countries]. However, previous studies have not clearly described any actual mechanism explaining how economic growth (e.g., an increasing GDP per capita) affects the selection of waste treatment options.

To understand such mechanisms, we conducted a more in-depth case study[1] of Bangkok, Thailand. In Thailand, GNI per capita (Atlas method, current USD) has grown from USD 1490 in 1990 to 1950 in 2000 to 5320 in 2013 [8]. The amount of waste generated in Bangkok was 9500 t day^{-1} in 2000, increasing to 12,600 t day^{-1} in 2012[2] (Table 1).

To address the problem of increased waste generation, in 2013, the Bangkok Metropolitan Administration (BMA), the local authority in Bangkok, signed a contract with Hong Kong-based C&G Environmental Protection Holdings Co. (hereafter, C&G) to introduce a 500 t day^{-1} incineration plant with power generation in Nong Khaem, Bangkok [12]. The contract provided C&G with a 20-year build-operate-transfer[3] concession.

The introduction of incineration facilities for municipal waste has been considered many times in Bangkok. For example, a Japan International Cooperation Agency (JICA) research team proposed incineration as an option in the 1990s, but the idea was rejected because of high costs [11]. In the 2000s, incineration was again considered by the BMA, but because of high costs and opposition by environmental non-governmental organizations (NGOs) for fear of dioxin pollution, this option was not pursued [13, 14]. In the case of C&G in 2013, however, the BMA signed a contract to move forward with incineration facilities. We thought the case of Bangkok would be a good case to study to better understand how changes in environmental, economic, social, and other conditions, including those resulting from economic growth, affected the selection of waste treatment options. This type of change also appears to be occurring in other developing countries in Asia (e.g., Malaysia is also currently considering incineration), and the results of the case study of Bangkok could contribute to policy development in other Asian countries.

Objectives and research framework

The objective and procedure of the study are outlined in Fig. 1. The objective of this study was to illustrate the structure of the mechanism of how economic growth, through the change of socio-economic factors, affected the selection of waste treatment options in Bangkok.

We targeted waste management in Bangkok from the 1990s to the present. We focused on landfilling, incineration, and composting because these are the three major options that have been considered in discussions of waste management in Bangkok during the target period. Landfilling was used as the base case when comparing waste treatment options because it was the current primary form of waste treatment.

First we conducted interviews of key relevant stakeholders to determine what kinds of changes in socio-economic factors from economic growth affected their decision (Method 1: the upper box in Fig. 1). We tried to investigate how the identified changes in the advantage and disadvantage of waste treatment options, associated with changes in socio-economic factors, and influenced the selection of waste treatment options.

Then, for interpretation and confirmation of the results from interview, we quantitatively estimated changes in environmental, financial, and social factors related to waste treatment options by using a combined life-cycle analysis (LCA) and cost analysis of changes (Method 2: the right box). We estimated environmental, financial, and social factors related to three waste treatment options in 1990,

[1] As Yin [9] noted, case studies are stereotyped as being the weak sibling among social science methods of study, but case studies are the preferred choice when posing "how" or "why" questions when investigators have little control over events. In our study investigating the relationship between economic growth and waste treatment options, we concluded that the case study approach was appropriate.

[2] We were unable to find data on the amount of waste generated in 1990. The amount of waste collected in 1990 was 5240 t day^{-1} [10]. According to a Japan International Cooperation Agency survey [11], 5043 t day^{-1} was generated and 4085 t day^{-1} was collected in 1989.

[3] A build-operate-transfer (BOT) concession is one of the so-called Private–Public Partnership financing schemes in which private companies build and operate a facility and then transfer it to a public entity after recovering the initial investment. Advantages of BOT for central and local governments include reduced development and infrastructure budget [15] and transfer of risk to the concession company [15, 16]. Advantages for the concession company include increased revenues, accumulation of operational experience [17], and better management of construction risks. The disadvantages of BOT include high sensitivity to the economic and political stability of the host country, high investment costs, possible changes in the government's foreign investment policies [17], and other factors. BOT projects require concession companies and all other participants to focus on the main purpose of the construction project, that is, the provision of a given facility at a specified price. The complex disputes this process generates require careful management [15].

Table 1 Waste generation, collection, and components in Bangkok in 1990, 2000, and 2012

		1990	2000	2012
The amount of waste generated (t day^{-1})		N.A.	9500	12,600
The amount of waste collected (t day^{-1})		5240	8988	9748
Component				
Food waste	–	13.70 %	46.88 %	48.41 %
Wood and leaf waste	–	4.93 %	6.77 %	6.46 %
Paper	R, N	16.20 %	8.66 %	7.67 %
Plastic	R, N	10.90 %	19.47 %	24.83 %
Foam	R	–	–	1.55 %
Glass	R	7.63 %	2.57 %	2.56 %
Rubber	N	1.80 %	0.11 %	1.40 %
Clothes/textiles	N	4.53 %	6.43 %	3.99 %
Stone and ceramic	N	–	0.51 %	0.65 %
Metal	R	4.13 %	1.49 %	1.72 %
Bone and shell	N	–	0.35 %	0.76 %
Other	–	36.17 %	6.76 %	0.00 %

Source: BMA

N.A. not available, *R* recyclable, *N* not recyclable

– this category was not included in the year

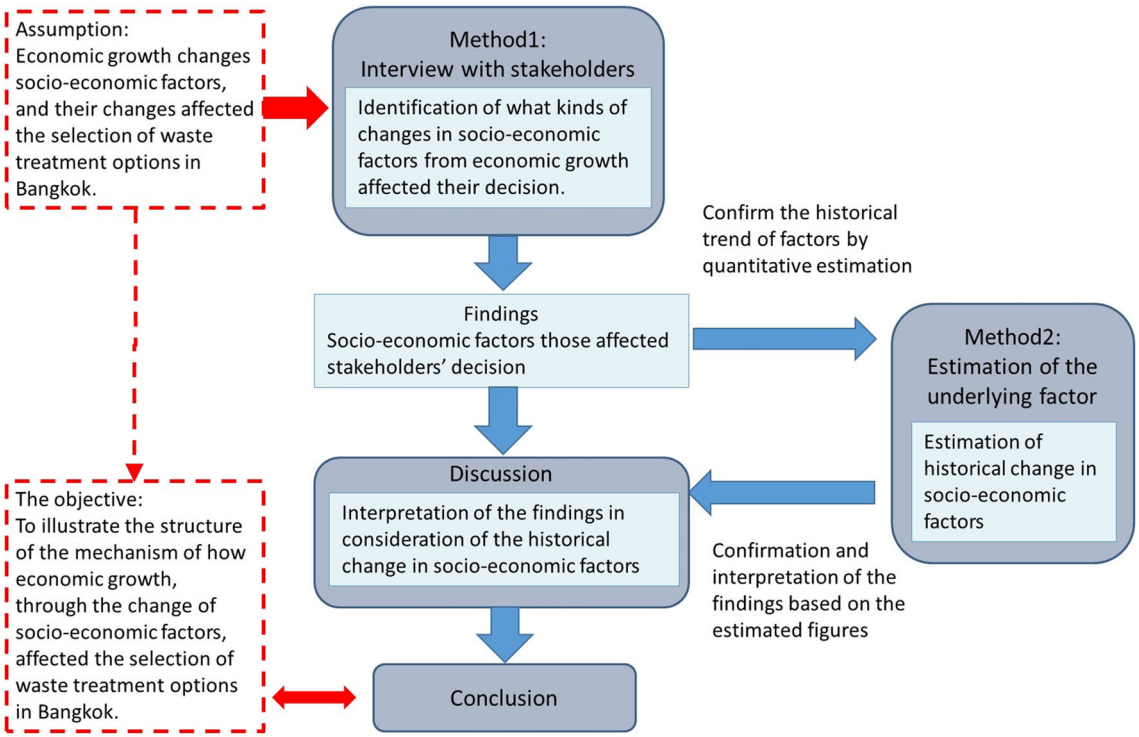

Fig. 1 Objectives and research framework of this study

2000, and 2012 and analyzed the differences in terms of their advantages and disadvantages.

The use of these two methods was necessary because we would have been unable to confirm and interpret the change of socio-economic factors behind the change of stakeholders' decision if we had only conducted interviews. Because our aim was to illustrate the entire structure of the mechanism of how economic growth affected the selection of waste treatment options, we therefore conducted both interviews and quantitative analyses.

Finally, based on the results of the interviews and our quantitative analyses, we identified the primary mechanisms for selecting waste treatment options in Bangkok.

Method 1: stakeholder interviews

Interviews were conducted in August 2014. Although the number of the interviewees was limited, the interviewees all were key people in charge of the selection of waste treatment options. The Solid Waste Disposal Division and the Policy and Planning Division in the BMA are primarily responsible for developing waste management policy in Bangkok. In the process of developing waste management policy, academic experts were asked to conduct studies and provide advice. In addition, the BMA's waste management policy needed to follow national waste management policy, which is developed by the Pollution Control Department (PCD) of the central government. Therefore, we conducted interviews with two high-level officials from the BMA (one was from the Solid Waste Disposal Division, which is in charge of waste disposal, and the other was in the Policy and Planning Division, which is primarily responsible for policy development), two experts from academia who conducted studies for the BMA and offered advice on the introduction of an incinerator, and two officials from the PCD (one is in charge of developing waste-to-energy policies and the other works on 3R policy). In addition, we interviewed a member of the 1990 JICA study team [11] to ascertain the waste management situation in Bangkok in 1990.

The interviews were semi-structured. Questions were related to the following aspects of waste management: (1) the current status of and challenges related to waste management in Bangkok (e.g., trends of waste generation, trends of waste treatment, awareness of local residents about issues related to waste management and local cooperation in waste separation, and challenges related to waste management); (2) waste management policy in Bangkok (historical trends and future perspectives); (3) points considered when developing waste management policy; and (4) how and why the BMA decided to introduce an incinerator. When we asked about (3), we requested respondent to consider the three pillars of sustainable development: environmental, economic (financial), and social factors.

We also asked interviewees about the global context of waste management (e.g., addressing climate change by reducing GHG emissions) to determine how global conditions affected the selection of waste treatment options.

Method 2: quantitative analysis of changes in factors according to economic growth

1. Boundary of waste treatment options and selection of factors.

For confirmation and interpretation of the findings from interviews, we conducted quantitative analysis. Before choosing the factors to be estimated, we clarified the boundaries of the three waste treatment options from treatment to final disposal as shown in Fig. 2. The capacity of the incineration plant and compost facility was set at 500 t day^{-1}, the annual operating period was 280 days (the capacity of C&G's incineration plant), and the annual total amount treated was 140,000 t $year^{-1}$ (500 t day^{-1} × 280 days). For simplifying analysis, we don't consider source separation. For landfilling, the target amount was set as 140,000 t $year^{-1}$ to allow direct comparisons of the different systems.[4] Collected waste is generally sent to transfer stations in Bangkok, and the route for collection was assumed to be the same for all three treatment options. We therefore excluded the collection process from the estimation boundaries.

When choosing the factors to be estimated, same as an interview, we considered the three pillars of sustainable development: environmental, economic (financial), and social factors. We also examined factors that had been used in previous studies, including those by Contreras et al. [18], Fujita and Tamura [19], Koizumi et al. [20], and Okumura et al. [7].

For environmental factors, we selected the amount of waste landfilled as well as greenhouse gas (GHG) emissions. Reducing the amount of waste landfilled has been recognized as a key challenge in developing previous waste management plans in Bangkok [11, 14]. Also, the Thai government is currently making a concerted effort to reduce GHG emissions [21], so we assumed that GHG emissions would also be an important factor in decision making in the field of waste management. Other potential environmental factors are odor, water pollution, and the emission of toxic substances into the surrounding environment, but they are difficult to estimate quantitatively.

Construction cost and operation and maintenance (O&M) costs were considered as financial factors. We also included revenues from the sale of electricity or compost. In addition, cost savings by avoiding new landfill construction were also considered because budget limitations for waste management were considered to be important issues to the BMA [10, 11, 22].

[4] We are aware that some waste treatment systems are more robust against changes in the amount of waste and have scale merits. We attempted to address these dynamic aspects of treatment options in interviews.

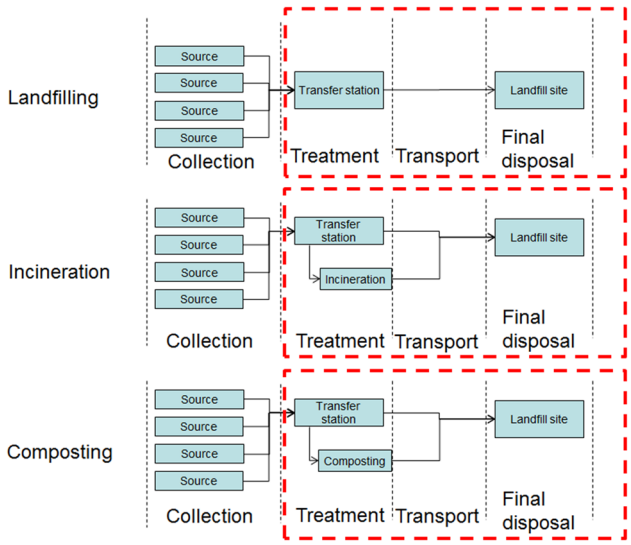

Fig. 2 Boundaries of waste treatment options examined

The numbers of workers in the formal and informal (e.g., waste pickers) waste management sectors were included as social factors, as was the effect on income in the informal sector. The informal sector was included because it has been recognized as an important issue in previous studies [e.g., 10, 13], and the role of informal sectors has recently been discussed in international conferences such as the Asia 3R Promotion Forum and Expert Meeting on Solid Waste Management in Asia and Pacific Islands. Acceptability among local residents is also an important social factor, but it is also difficult to estimate quantitatively. We therefore did not estimate this factor but did discuss this topic in the interviews.

2. Estimation of the underlying factors.
   The respective environmental, financial, and social factors were estimated as follows. Detailed estimation procedure is described in the electronic supplementary material.

   (a) Environmental factors.
   As mentioned above, the environmental factors estimated were the amount of waste landfilled and GHG emissions. In the case of composting, the amount of waste landfilled was the amount of waste collected minus the amount composted. In the case of incineration, the amount of waste landfilled was the amount of waste collected minus the amount incinerated plus the amount of ash generated by incineration.
   GHG emissions were calculated as the sum of (a) methane generation from the landfill site, (b) methane and nitrous oxide generation from composting, (c) CO_2 generation from the incineration of plastic, and (d) CO_2 reduction from electricity displacement, according to the United Nations Framework Convention on Climate Change (UNFCCC) methodological tool published in 2012 [23].

   (b) Financial factors.[5]
   Construction costs and O&M costs for the incineration plant, composting plant he landfill site are estimated based on the various previous study [11, 12, 24–29].
   The revenue generated from the sale of power was estimated by multiplying the power generated and the electricity price [30–32]. The revenue from the sale of compost were estimated as the product of the amount of compost generated and the price of compost in Thailand [33]. The amount of compost available for sale was estimated to be 30 % of the amount of waste composted, which is the average yield at an existing composting plant in Bangkok [33].
   The cost saving by avoiding new landfill construction was calculated by multiplying the amount of waste reduction (relative to the landfilling case) and the unit construction costs for the landfill facility (from the data provided in the 1990 JICA study [11]). Costs in the later years were adjusted for inflation relative to land prices, equipment prices, and labor costs.

   (c) Social factors.
   The number of workers at landfill facilities was estimated as the sum of the numbers of additional formal and informal workers hired for the landfill facility. Formal staff hired for the landfill site was based on the data provided by the 1990 JICA study [11]. The number of workers in the informal sector (waste pickers at the landfill sites) was based on a study by Muttamara et al. [10].
   Income day^{-1} person^{-1} in informal sector was set at 75 baht in 1990 according to Muttamara et al. [10], 100 baht in 2000 according to Sasaki [13], and 137 baht in 2012 by adjusting the value from 2000 for inflation. Then, we estimated income in the informal sector as the number of workers in the informal sector multiplied by income day^{-1} person^{-1}.

[5] Detailed explanation of procedure of estimation are provided in Table A1 in the electronic supplementary material.

Results

Stakeholder interviews[6]

In general, both the BMA officials, PCD officials, and the academic experts had similar opinions in most of the categories. Regarding the first set of questions about the current status and challenges of waste management in Bangkok, BMA officials and the academic experts emphasized increased waste generation and scarcity of landfill sites. They explained that scarcity of waste landfill sites became a serious problem in the late 1980s. They noted that private waste management companies took over the task of waste disposal from the BMA at this time, solving the problem temporarily in the 1990s; however, waste generation continued to increase. The BMA officials stated that, since the late 2000s, they had begun to think that the current waste management situation was potentially unstable because waste disposal was managed by only two companies. The officials said they thought if these companies suddenly decided to stop receiving waste, the waste generated in Bangkok would accumulate within the city. The BMA officials also stressed the residents' generally low awareness of waste sorting, which they believed to be a root cause of poor source separation and a lower quality of compost. BMA officials noted this made finding a market for the compost much more difficult.

Regarding the second group of questions about waste management policy in Bangkok, the BMA officials and researchers noted that the BMA was trying to diversify waste treatment options to reduce the risk of a sudden stoppage in the two private companies' acceptance of waste. They also pointed out that a waste treatment option that decreases the amount waste being landfilled would be a huge benefit to the BMA.

For the third set of questions about points considered for developing waste management policy, the BMA officials and academic experts mentioned that, among the environmental factors, reducing the amount of waste being landfilled was very important. They added that this has been an important issue for the BMA historically. The BMA officials and academic experts said that other environmental factors, such as odor and waste pollutants in leached water, were not viewed as important to them.

The two BMA officials and two academic experts mentioned that cost was important in the selection of waste treatment options. They also emphasized that cost affected the selection of waste treatment options in Bangkok in a complicated way. In Thailand, the Private Investment in State Undertaking Act (referred to as the "PPP Act") regulates large-size investment projects. In the case of a waste treatment plant, a municipality leases land for a private company to build and operate a plant. This land lease is deemed to be the public sector's investment under the Act. If a project has a capital cost of more than one billion (10^9) baht, an investor needs approval from the Thai Cabinet before the start of the project. For approval, the investor has to conduct a detailed feasibility study. This process requires at least 2–3 years to complete. The BMA officials stated that the cost of the incineration plants was over that threshold in the 1990s and early 2000s, so even if the BMA had wanted to introduce an incinerator in the 1990s and 2000s, its introduction would have been restricted by the PPP Act, thereby making the process even more difficult. Chinese incinerator companies have recently proposed incineration plants costing less than one billion baht. The BMA officials and academic experts said that this lower price allowed the BMA to go forward with the incinerator project without enduring the long and complicated process specified in the PPP Act.

The BMA officials noted that O&M costs and avoidance of new construction of landfill sites were not important to them. The operation and management of waste treatment and disposal are conducted by private companies for reasons of cost efficiency and limited governmental resources. They mentioned that, although landfilling and composting had an advantage in terms of O&M costs as compared with incineration, they did not consider the advantage in the selection process. The BMA officials also did not consider revenues from the sale of power or compost because it was not their responsibility.

The BMA officials and researchers mentioned that social factors such as impacts on employment and income of the informal sector were not key decision factors for them. On the other hand, the BMA officials stated that the acceptance of the facility by nearby residents was very important.

One BMA official (the one from the Policy and Planning Division) and one PCD official (the one in charge of waste-to-energy policy) mentioned that factors related to the global environment, such as GHG emissions, affected the selection of waste treatment options. They said that a high price premium was introduced for electricity generated by incinerators, which provided incentive for waste-to-energy projects.

One BMA official (from the Policy and Planning Division) and one PCD official (in charge of 3R policy) also pointed out that development of social media also affected the selection of waste treatment options. Previously, even when fires occurred at landfill sites in Thailand, only neighboring people knew about it. The officials said that news of a recent fire quickly spread through social networking services such as Facebook and Twitter, and many

[6] In this section, we describe only the answers from interviewees. Our interpretations are discussed in the next section.

people became aware of it. Consequently, they mentioned that more people were against the development of a new landfill site in their neighboring area. Dioxin contamination was also an issue in the development of the new incinerator.

One BMA official (from the Policy and Planning Division) and one PCD official (in charge of 3R policy) said that, in the past, NGOs had been residents' sole information source about incineration technology. Currently, however, people can easily obtain technological information through the Internet. The officials mentioned that some NGOs were still against the introduction of an incinerator, but people came to be less opposed to it.

Regarding the fourth set of questions, on how and why the BMA decided to introduce a waste-to-energy facility, the two BMA officials stressed that the decision was agreed to by the Mayor of Bangkok following the policy direction of the Prime Minister of Thailand. The BMA officials said that, without the support of these high-level officials, introducing the incinerator would have been difficult. The BMA officials again stressed that the introduction of the price premium for incinerator-generated electricity was an important factor in the BMA's consideration of the incinerator project. They also stated, as previously noted, that the avoidance of the barriers presented by the PPP Act was also a key factor.

Estimation of factors and changes in benefits that affected the BMA's decision

The estimation results of the environmental, financial, and social factors are summarized in Table 2.

(a) Environmental factors.

As shown Table 1, total waste generation actually increased, but in landfilling case, the amount of waste landfilled remained at 140,000 t in 1990, 2000, and 2012 (Table 2) because the estimations were made assuming a facility capacity of 500 t day^{-1}. In the composting case, only the organic waste component was composted and the remaining waste was landfilled: 114,000 t was landfilled in 1990[7]; 65,000 t in 2000; and 63,000 t in 2012. In the case of incineration, 9000–23,000 t of ash was sent to the landfill site annually. In all years, the amount of waste being landfilled was much smaller in the incineration case than in the composting case.

GHG emissions in the composting case were smaller than in both the landfilling and incineration cases. The increase in the percentage of food waste contributed to the increase in methane generation over time in the landfill case. In both the compost and incineration cases, there is no methane gas generation from the landfill site because residue sent to landfill site does not contain organic material. In 1990, the percentage of the "other" category in waste was high (36.17 % in 1990 as compared to 6.76 % in 2000 and 0 % in 2012). Some organic waste may have been included in this "other" category, so more methane would be generated from the landfill site than is shown in Table 2. The recovery effect of incineration and composting would also be higher than the values listed in Table 2 if this were the case.

(b) Financial factors.

The construction cost of the landfill sites and composting plants increased from 1990 to 2012 in accordance with increases in land prices, equipment prices, and labor costs. However, the construction cost of incineration plants decreased from 2000 to 2012 because C&G proposed a lower price. In 1990, the construction cost of an incineration plant was about eight times that of a composting plant. However, in 2012, the construction costs of the incineration and composting facilities were almost equal.

O&M costs about doubled in all three cases from 1990 to 2012, primarily because of increased fuel prices, equipment prices, and labor costs. The O&M cost of composting was approximately three times that of landfilling, and that of incineration was approximately seven times that of landfilling.

In 1990 and 2000, the energy value of waste was less than 1500 kcal kg^{-1}, which was too low to generate electricity, so no revenue was gained from the sale of electricity in those years. The proportion of plastics in the waste increased in the 1990s and 2000s, contributing to an increase in the energy value of waste. The value was continuously greater than 1500 kcal kg^{-1} after 2000 and was high enough (more than 1700 kcal kg^{-1}) in 2012 to make power generation feasible. Sales of compost increased over time, but the increase was not nearly as significant as revenues from the sale of electricity in the incineration case.[8] In 2012, incineration generated approximately five times the amount of revenue as compared with composting.

[7] In 1990, some organic waste may have been included in the "other" category. It is possible that landfilled amount could be reduced with more sophisticated segregation.

[8] The revenue from composting in 1990 would increase if more organic matter can be recycled by more sophisticated segregation of "other" category.

Table 2 Estimated value of factors for each waste treatment option for 1990, 2000, and 2012

	Environmental		Financial				Social		
	Amount of waste landfilled (thousand t year^{-1})	GHG emissions (thousand t-CO_2 per 10 years)	Construction cost of a corresponding waste treatment facility (million baht)	O&M cost of a corresponding waste treatment facility (million baht year^{-1})	Revenue from sales of electricity/compost (million baht year^{-1})	Cost saving by avoiding new landfill construction (thousand baht year^{-1})	Impact on employment		Informal sector income (million baht)
							Number of employees in the formal sector (persons)	Number of informal employees (persons)	
Landfill (1990)	140	1162	27	11	0	0	40	245	5.2
Landfill (2000)	140	3392	51	17					7.0
Landfill (2012)	140	3471	80	23					9.6
Composting (1990)	114	5	185	32	16	7	36	200	4.3
Composting (2000)	65	14	287	49	45	36	22	114	3.2
Composting (2012)	63	15	890	68	46	48	21	110	4.3
Incineration (1990)	23	96	1535	100	Electricity cannot be generated	32	92	40	0.9
Incineration (2000)	9	96	1891	114	Electricity cannot be generated	63	88	16	0.4
Incineration (2012)	9	75	900	158	Max 217	82	88	16	0.6

Fig. 3 Differences among waste treatment options as compared with landfilling

The cost saving by avoiding new landfill construction increased because of inflation in various costs related to the construction of landfills. The cost saving was larger in the incineration case relative to the composting case, primarily because of the lower amount of waste landfilled in the incineration case.

(c) Social factors.

Forty formal workers were estimated to be required for a landfill site with a capacity of 500 t day^{-1}. Fewer landfill workers were needed in the composting and incineration cases because of reductions in the amount of waste landfilled. A new composting plant required only a few workers for operation based on the experiences of other similar plants in Japan (such as those in Tsuruoka and Odate). We assumed the three persons (average of Tsuruoka and Odate) required for O&M for composting plant. The 1990 JICA study [11] estimated that 85 formal workers would be required for the O&M of a 600 t day^{-1} incinerator. Obviously, many more workers are necessary in the incineration case than in the composting case.

The number of workers in the informal sector was 245 persons for 500 t day^{-1} in the landfill case, 110–200 persons in the composting case, and 16–40 persons in the incineration case, all of which worked at the landfill.

The informal sector earned 5.2–9.6 million baht in the landfill case and 3.2–4.3 million baht in the composting case. Informal income in the incineration case was much lower: 0.9 million baht in 1990, 0.4 million baht in 2000, and 0.6 million baht in 2012.

(d) Advantages and disadvantages of waste treatment options.

Figure 3 shows differences between incineration and composting relative to landfilling. In 1990, composting was superior to incineration across many factors, including reduction of GHG emissions, construction cost, O&M cost, sales of electricity or compost, and increase/decrease in the number of workers (formal plus informal). However, the superiority of composting decreased over time. An especially notable example is in construction cost, where the costs became almost the same in 2012. Incineration also gained a large advantage in terms of sales of electricity in 2012 when electricity generation from incineration became feasible for the first time.

Discussion

Based on the results of the interview, we illustrated whole structure of the complicated relationships of economic development; environmental, economic, and social conditions; and changes in the advantages and disadvantages of various waste treatment options in Bangkok as shown in Fig. 4. We also could confirm part of the structure by the result of quantitative estimation.

We discuss Fig. 4 beginning with the factors in the top left corner in the "Economic development" box and work our way down from there. Increases in labor costs and fuel prices raised O&M costs for composting and incineration as did waste transportation costs. Actually, the result of quantitative estimation confirmed the increase of O&M cost in all waste treatment options, in particular much more increased in composting. However, according to the result of interviews, key relevant stakeholders did not recognize

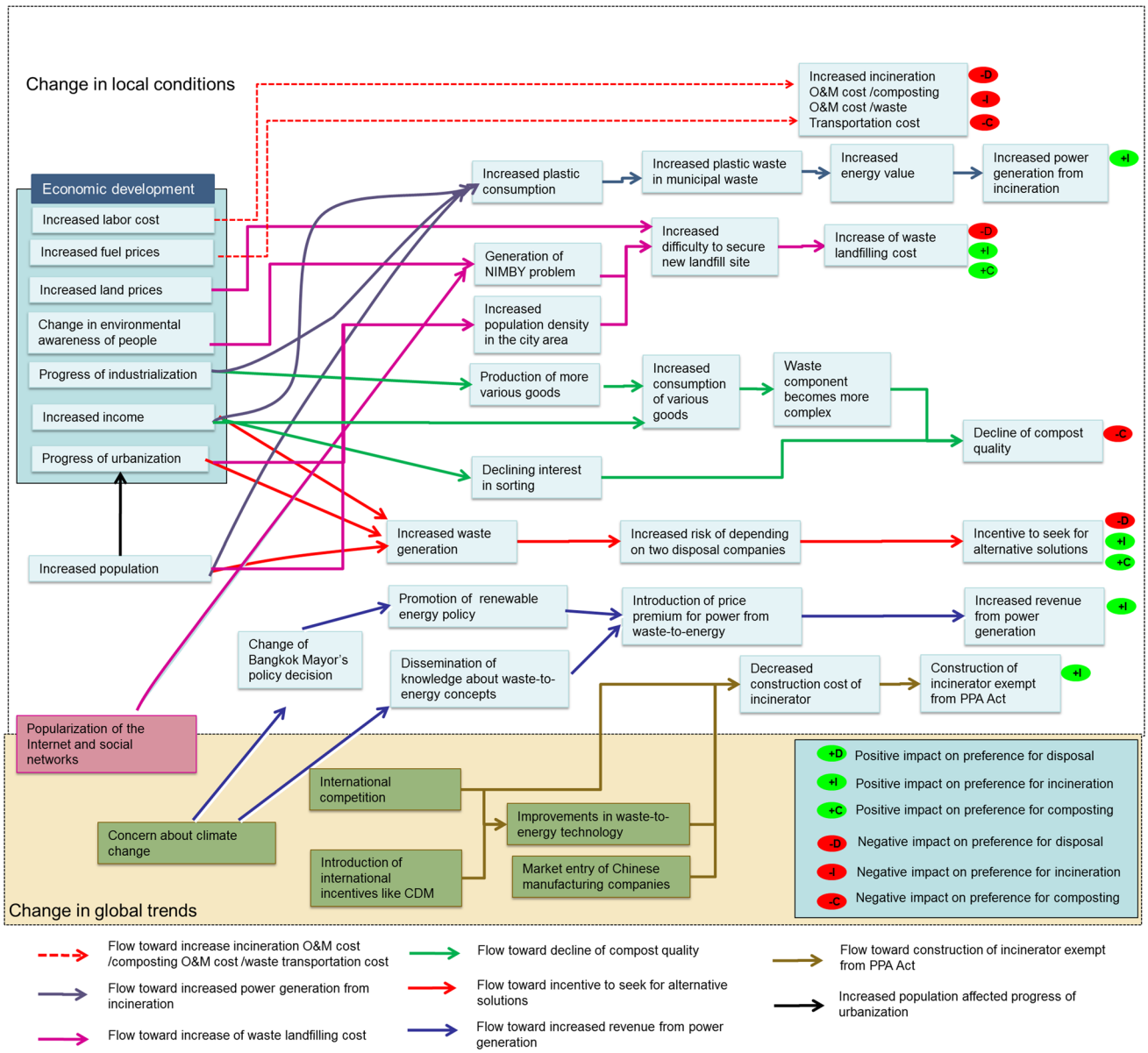

Fig. 4 Diagram of decision-making factors that affected the selection of a waste treatment plant in Bangkok

O&M cost as important factors for their decision of selecting waste treatment options.

According to the interview, we found that in the late 1980s, difficulty of finding new landfill site was very serious challenge for BMA. As described in Fig. 4, increased land prices as shown in Fig. 5 made it more difficult to build a new landfill site. Increases in both urbanization and population raised the population density in the central city area, which also made it more difficult to find new land for a landfill site. A changing level of people's environmental awareness of the consequences of economic development brought about not in my backyard (NIMBY) opposition and made the installation of new landfills even more difficult, which resulted in additional landfill costs. Composting and incineration facilities can be located at existing transfer station sites; therefore, there is no need to find new sites for the composting and incineration facilities. Consequently, as confirmed by the quantitative estimation, the relative merit in the amount of waste landfilled, of incineration and composting increased as opposed to landfilling.

The result of interview also stressed that power generation from the incineration of waste was very important factor for selecting incineration. A generally increasing level of industrialization, rising incomes, and increasing population all contributed to increased consumption of plastic, which in turn, raised the energy value of waste as discussed previously. The higher energy value of waste

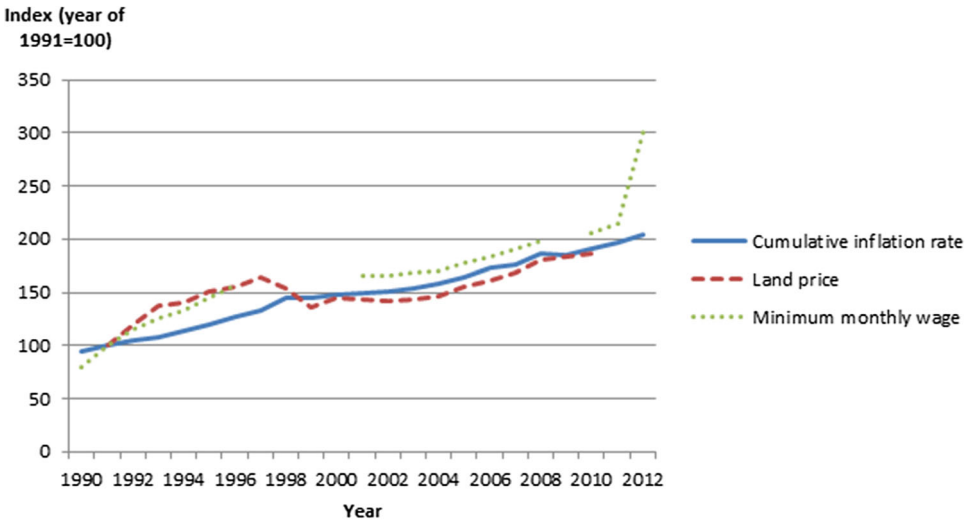

Fig. 5 Trends for the cumulative inflation rate, land price, and minimum wage

eventually enabled power generation from the incineration of waste. This greatly enhanced the relative merit of incineration because revenue could be earned from the sale of the power generated as underlined by the result of quantitative estimation.

On the other hand, poor quality of compost discouraged introduction of composting. Increases in industrialization, income, and population also resulted in increased production and consumption of a greater variety of goods. The waste stream therefore became more complex and it became difficult to keep the quality of compost. Also, increased income appears to have weakened people's interest in sorting and degraded the quality of compost. The degradation of the quality of compost has a negative effect on the relative merit of composting because poor quality compost is more difficult to sell and thus sells at a lower price. Quantitative estimation shows that revenue from selling compost is 46 million baht year^{-1}. If compost price decrease, this figure also will decrease substantially.

Many key relevant stakeholders argued that the increase of waste generation was also a driver for selecting an incineration. The amount of waste generated in Bangkok increased for a variety of reasons. The increase raised the level of dependency on the two private disposal companies in Bangkok. If the two companies were to stop receiving waste, a huge amount of waste would accumulate in the BMA. It increased the officials' desire to diversify waste management options.

The result of interviews also revealed that not only local changes but also global changes affected the selection of waste treatment options in Bangkok. As mentioned by the BMA officials, concerns about global warming contributed to encouraging the Mayor of Bangkok's decision to introduce incineration in 2013. Concerns about the effects of climate change also had a positive impact on dissemination of knowledge about waste-to-energy technology. Promotion of renewable energy policies at the national level and greater dissemination of knowledge promoted the introduction of a price premium for power produced with waste-to-energy technology. The introduction of a price premium increased revenues from power generation, which had a positive effect on the selection of incineration.

Some general global trends not directly related to Bangkok, such as international competition and the introduction of the clean development mechanism (CDM), contributed to improvements in waste-to-energy technology [34], which in turn, contributed to cost reductions in incinerator facilities and had a positive effect on the introduction of the incinerator facility in Bangkok. The quantitative estimation also revealed that composting and incineration can achieve huge reduction of GHG emission. This brings huge additional financial merit from CDM.

As stated previously, the market entry of a Chinese manufacturing company, in line with international competition, decreased construction costs, and the resulting cost reduction exempted the construction of the new incinerator plant from the PPP Act and facilitated the BMA in selecting the incinerator option. The popularization of social networks (SNS in Fig. 4) also exacerbated the NIMBY problem through greater and much easier dissemination of knowledge and information. This resulted in increased waste disposal costs because it became more difficult to secure a new space for disposal.

Key stakeholders did not consider social factors much as the other factors. The result of quantitative estimation also could not show the significant impact on employment and on informal sector income as the environmental and financial factors.

Conclusion

This case study of Bangkok illustrated the mechanism by which economic growth affected the selection of waste treatment options. Economic growth caused changes in various prices (e.g., that of fuel, labor, and land), people's activities and perceptions, in the amount of waste generated, and the characteristics of wastes. Growth also had effects on other environmental, financial, and social factors examined in this study (e.g., GHG emissions, construction and O&M costs, and income in the informal sector). However the result of study revealed that some of the change of factors such as construction cost and revenue from power generation, etc. affected key relevant stakeholders' decision substantially but the others factors such as O&M costs, and income in the informal sector did not affected the decision.

In addition, specific local conditions that influenced the selection of waste treatment options were also affected by economic growth. In the case of Bangkok, the BMA depended on two private companies for waste disposal. The increased amount of waste generated that resulted from economic growth made the BMA's dependency on only two companies even more risky, and the BMA attempted to reduce risk by introducing the incineration facility.

Global economic and technological trends also affected waste treatment policy in Thailand. Growing concerns over the effects of climate change were important factors influencing the introduction of an incineration plant in Bangkok. Notably, these concerns changed policymakers' perceptions of the benefits of incineration with power generation. CDM, an international mechanism providing incentives to introduce waste-to-energy technologies, contributed to progress in the development of waste-to-energy technologies. International competition among incineration plant manufacturing companies and the market entry of a Chinese manufacturing company also decreased the cost of constructing an incinerator. Although waste management tends to be discussed in a local context, the results of this study illustrated the importance of the global context as well.

The study is only a case study of Bangkok. More case studies in other cities in Asia are needed to identify a more general mechanism for selection of waste treatment options, which may contribute to improved policy decisions about waste management in Asia.

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