System dynamics simulation on municipal solid waste in Hong Kong

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The municipal solid waste (MSW) generation in Hong Kong (HK) is increasing at a rapid pace, resulting in health and environmental issues for the public. Compared with Singapore and Shanghai, HK has a higher MSW generation rate due to less effective measures and government policies. To forecast the MSW generation and recycling in HK, system dynamics modelling was conducted using Vensim 6.0, based on the data collected from semi-structured interviews and official reports in the Environmental Protection Department of HK, the National Environmental Agency Singapore and Shanghai Environmental Protection Agency that regularly provide statistics on waste outputs. The simulation results show that shortly the MSW in HK will increase based on the current growth rates, and along with that, recycling will also increase. The recycling rates will offset that of the MSW generation due to the closure of landfills, and MSW will be effectively recycled due to more advanced disposal techniques. The strategies developed by the HK government will be able to manage the MSW disposal, but the city will experience more severe MSW conditions in the future as its landfills are expected to close earlier than planned. Recommendations for HK to deal with MSW generation were derived from the experiences in Singapore and Shanghai.

1. Introduction

Municipal solid wastes (MSWs) are those substances discarded within the municipal area (Wei *et al.*, 2017). The main sources of MSW vary but include commercial, residential, industrial or institutional; each of these can be further segregated into different categories based on the physical composition of wastes (Baawain *et al.*, 2017; Lavee and Khatib, 2010). MSW is a significant issue for Hong Kong (HK) as the MSW amount is increasing at a rapid rate (Ling, 2015). The composition and amount of MSW are determined by factors such as population, income, household size, emigration rate and economic conditions (Cai *et al.*, 2014). The land area in HK is less than 259 square kilometres, but is home to about 7.18 million people. Currently, HK has only three operating landfills and 13 closed landfills (Hong *et al.*, 2010). In 1998, the HK government published a framework on waste reduction to set-out initiatives for the reduction of waste in the city (Chung *et al.*, 2010). After some trials testing the effectiveness of different waste management strategies, a territory-wide programme was developed in 2005 to facilitate the separation of waste in buildings (Chung *et al.*, 2010). The waste disposal ordinance in 1980 provided the statutory framework to manage all types of wastes in HK, which offers licenses for waste collection and disposal facilities (Chan, 2001). The government of HK also developed and enacted the product eco-responsibility legislation in 2008 to manage MSW in the city (Chen *et al.*, 2013). MSW refers to the waste generated by humans in their daily lives (Lee *et al.*, 2016) excluding construction and demolition waste, chemical waste and some special industrial wastes (Prades *et al.*, 2014). The increasing

population results in an increase in waste so that the projection of waste generation becomes a critical issue for many cities (Wang *et al.*, 2011). With fast economic development, humans tend to generate more waste, especially when people can spend more and consumption increases (Hong *et al.*, 2017). MSW is piled up and is gradually becoming a major problem due to the complexity in collection and treatment (Lavee and Khatib, 2010). The rapid increase in MSW has stirred up problems such as public health and environmental changes (Antmann *et al.*, 2013).

One of the most common methods used to deal with MSW is landfilling, which has been adopted by many cities around the world leading to the lack of sufficient lands and a strong emergence of landfill gases (Bernstad, 2014). The landfill emissions lead to odour pollution and respiratory diseases (Chowdhury, 2009). HK set the target to raise the MSW recovery from 34% in 2002 to 36% in 2004, 40% in 2007 and then 50% in 2015. As a comparison, Florida in the USA has decided to increase the MSW recovery rate to 75% by 2020 (Liyana *et al.*, 2015). The Environmental Protection Department (EPD) of HK keeps regular statistics on each type of waste. The analysis of these statistics is important as it allows evaluation of whether the system is working properly. System dynamics (SD) is a robust tool that can use these statistics and provide a comprehensive simulation of the waste management process (Kollikathara *et al.*, 2009). According to Machowski *et al.* (2008), SD focuses on the feedforward and feedback relationships, and it develops relationships between rate variables and stock variables. SD analyses problems and allows analysis of

complex, non-linear relationships aided by computer simulations to conceptualise and to rationally analyse structures and interactions and to prognosticate their effects in a holistic way (Inghels and Dullaert, 2010). The HK's daily domestic waste generation rate per capita is much higher than that of other Asian cities such as Shanghai and Singapore. HK is running out of landfilling spaces earlier than planned and the current landfills will be exhausted by 2020 (Liyanage *et al.*, 2015). There is an urgent need to forecast the rapid increasing MSW in HK and to provide accurate modelling for control purposes. In the past, researchers focused on gross domestic product (GDP) as the only indicator of waste generation; however, according to Lam and Chan (2014), other factors such as infant mortality, labour force size, population density and life expectancy should be included. By analysing the historical and current MSW statistics in HK and other Asian cities such as Singapore and Shanghai through interviews and documentation research, this study develops a SD simulation to forecast the future MSW generation in HK for control purposes. A comparison and contrast of MSW analysis between HK, Singapore and Shanghai are provided.

2. MSW in HK

The MSW loads in HK were increasing since the year 1986. HK's MSW comprises of over 70% solid waste, and the daily waste disposal has reached 311 t (Han *et al.*, 2014). Waste recycling is more complex than its reduction. In 1998, the HK government launched the Waste Reduction Framework Plan, which provided a variety of initiatives to reduce waste and recommended a series of measures to promote MSW separation and segregation in HK (Jaillon *et al.*, 2009). The plan was to improve the overall MSW recovery rate from 34% in 2004 to 40% in 2007 and to increase the household waste recovery rate from 8% in 2004 to 20% in 2007. The HK government published the first sustainable development strategy in 2005, including a policy framework for MSW management in HK (Zhang *et al.*, 2012), which proposes a simple and effective tool to create incentives for the community to recycle more and to discard less (Han *et al.*, 2014). For example, the government levies a scheme to direct the economic incentives to reduce the use of plastic shopping bags in the city (Lu and Yuan, 2013).

According to Yu *et al.* (2013), the EPD in HK manages collecting, treating, disposing and transferring MSW in the city; more than HK\$10 billion (HK\$1 = £0.10) has been invested in MSW facilities to manage the waste. The waste disposal ordinance was used to control the waste disposal including export and import (Yu *et al.*, 2013). The three operating landfills are located in the new territories, namely: Nim Wang, Tseung Kwan O and Ta Kwu Ling. Thirteen out of 16 landfills in HK have been closed and restored for several uses to

minimise potential health risks. For example, some were landscaped to offer green zones and recreational uses such as golf driving ranges, grass pitches and ecological parks.

There are seven refuse transfer stations located in different areas but with centralised collection points. The waste from smaller refuse collection trucks is compacted and transferred into containers and shipped to landfills through lorries. The chemical waste treatment centre on Tsing Yi Island accepts different chemical and clinical waste. The Sha Ling Composting Plant in the northern new territories accepts livestock waste and composts it into soil suitable for the use in the city. With the efforts of the government and community, the waste recovery rate in HK has been increasing, and over 80% of the HK population has been involved in the waste separation programme (Yau, 2010). Materials in MSW such as paints, plastics, disposed goods and inks are considered hazardous (Wei *et al.*, 2017), and the waste management occupies the uppermost rung in the hierarchy of waste management (Zhou *et al.*, 2015). The hierarchy refers to those activities undertaken with an item before it is perceived as waste, which includes the decrease of total waste produced, the decrease in the associated environmental impacts on the public and the decreased quantity of noxious objects (Gidarakos, 2015). Some effective methods for waste reduction include adjustments in the usage of raw materials and the adoption of a suitable production process (Gidarakos, 2015).

3. MSW in Asian cities

Asian cities such as HK, Singapore, Shanghai, Taiwan and Beijing are among the leading cities regarding both economic development and waste generation. The city GDP per capita in some Asian megacities such as Bangkok, Shanghai, Jakarta, Manila, Beijing and Kuala Lumpur is two- to five-times higher than other cities. The estimates of expected typical values for MSW in some Asian cities are listed in Table 1. High- and middle-income cities (such as HK, Singapore, Tokyo, Taipei, Seoul, Bangkok, Kuala Lumpur, Beijing and Shanghai) have a

Table 1. Estimated material consumption and waste generating in Asian cities (Ali and Sion, 2014)

Asian cities	Daily material consumption: t	Daily municipal solid waste: t
High-income cities: HK, Singapore, Tokyo, Taipei, Seoul	6000–14 000	500–750
Middle-income cities: Bangkok, Kuala Lumpur, Beijing, Shanghai	4000–6000	250–550
Low-income cities: Manila, Jakarta	3000–5000	50–250
Rural areas in middle-and-low income regions	500–2000	120–200

Table 2. HK compared with some Asian cities (Ali and Sion, 2014)

City	Agriculture area: km ²	Forest area: km ²	Marine area: km ²	Total area: km ²	Urban density: people per km ²	MSW per km ² city area: t/km ²
HK	1800	2100	20 000	23 900	57 000	1400
Guangzhou	1000	700	5000	6700	2400	16
Bangkok	800	300	10 000	11 100	10 000	110
Beijing	600	150	5000	5750	20 000	110
Rural area	500	50	2000	2550	n.a.	n.a.
Basic cities	5000	1800	13 300	20 100	10 000	200

daily material consumption from 4000 to 14 000 t and this creates a daily MSW at around 250–750 t. On the other hand, low-income cities such as Manila and Jakarta have a much lower daily material consumption and a MSW generation. The middle- and low-income rural regions have a daily material consumption ranged from 500 to 2000 t, and MSW generation from 120 to 200 t (Ali and Sion, 2014). Table 2 shows that HK has higher agriculture, forest, marine and urban density than other cities such as Guangzhou, Bangkok and Beijing.

4. Research procedures and steps to develop system dynamics model

SD is a robust process used to analyse complex systems aided by computer simulation. SD can accommodate internal feedback loops and time delays, such as required when forecasting on MSW generation and control. The process of a SD model starts with identifying the parameters; in this study, the parameters refer to those factors for waste generation (Liu and Li, 2015). In the past, researchers only focused on GDP as an indicator for waste generation, but Lam and Chan (2014) have suggested that additional factors should be included, particularly (a) population, (b) household size, (c) standard of living and (d) purchasing power. Hong *et al.* (2010) conceptually describe the relationship between these parameters and MSW generation as higher economic growth leads to higher public spending, which increases the waste generation; higher income leads to higher waste generation; and, more population generates more MSW. HK is a highly populated city with 6650 persons per square kilometre. The median monthly domestic household income is around HK\$22 400, and it is increasing; the total labour force is around 3.86 million people (Cai *et al.*, 2014). In this study, data for SD modelling were collected from semi-structured interviews and official reports in the EPD of HK, Shanghai Environmental Protection Agency and the National Environmental Agency Singapore, which regularly provide statistics on daily/monthly/annual waste outputs in their cities. The Vensim 6.0 software package was used to simulate the dynamic process of the system.

The first step in generating the dynamic simulation was developing the stock-and-flow diagram by defining the variables

influencing on MSW generation using the box variable function and rate variable function in Vensim 6.0 as shown in Figure 1. MSW generation is the box variable, and MSW increase rate and MSW decrease rate are the rate variables. The second step was to identify the variables influencing the values. Step 3 is based on the causal loop diagram among variables such as household waste increasing rate, MSW generation per household and household spending per capita rate. The MSW decrease rate was determined in step 4. Step 5 develops causal loop diagram towards the MSW disposal volume, resulting in the decrease in the landfill rate. MSW disposal volume is the starting point followed by MSW recovery rate, total waste disposed and MSW disposal. Step 6 defines the stock-and-flow diagram for landfill in HK, where landfill is a box variable. The simulation as developed at this step could determine the amount of waste disposed at landfills to forecast future waste. Step 7 integrates causal loop diagrams and stock-and-flow diagrams to finalise the SD model.

5. Finding and results

5.1 Limitations of previous research

Chung (2010) conducted research to forecast MSW in HK until 2036, based on GDP and a linear relationship between GDP growth and MSW increment; a correlation between MSW generation and the population was found to be useful. However, Chung (2010) also identified a key limitation: using GDP for predictions is inaccurate, and it may overestimate the actual quantities of MSW generation. As evidence of this limitation, Table 3 (by Chung, 2010) shows the comparison between the projected quantities based on GDP and the actual quantities of domestic waste disposal.

5.2 Territorial waste disposal rates and quantity of MSW disposed and recovered

The GDP per capita (Table 4) and MSW disposal rate and domestic waste disposal rate (Table 5) were collected from the EPD of HK, which regularly monitors MSW in the city. The MSW disposal rate is increasing on a yearly basis. For example, the MSW disposal rate was 1.28 kg/d in 1991 but increased to 1.33 kg/d in 2013. On the other hand, the

Figure 1. A seven-step SD modelling for MSW forecasting

Table 3. Waste predictions by Chung (2010)

Forecasts	Projected quantities	Actual quantities
Forecasts from 1998 study		
MSW in 1996: t/d	14 500	8140(+)
MSW in 2001: t/d	18 600	9300(+)
MSW in 2006: t/d	23 400	9279(+)
Forecasts from 1989 to 1900 study		
Per capita domestic waste disposal rate in 2001: kg/d	1.3	1.12(+)
Per capita domestic waste disposal in 2001: kg/d	1.33	1.12(+)
Forecasts from 1993 to 1994 study		
Per capita domestic waste disposal in 2006: kg/d	1.5	0.97(+)
Forecasts from 1995 study		
Domestic waste in 2001	7830	7551(+)
Domestic waste in 2006	9690	6634(+)
Forecasts from 1996 study		
Per capita domestic waste disposal in 2001: kg/d	1.25	0.97(+)
Forecasts from the 1998 study		
Domestic waste in 2001	9150	6635(+)
Domestic waste in 2006	7460	7551(–)
Domestic waste in 2006	8430	6634(+)
Forecasts from 1998 study		
Domestic waste in 2006	10 090	6634(+)

Table 5. MSW disposal rate and domestic waste disposal rate

Year	MSW disposal rate: kg/d	Domestic waste disposal rate: kg/d
1991	1.28	0.97
1992	1.37	0.99
1993	1.43	1.02
1994	1.40	1.01
1995	1.27	1.01
1996	1.26	0.97
1997	1.34	1.04
1998	1.33	1.04
1999	1.40	1.12
2000	1.40	1.13
2001	1.39	1.12
2002	1.40	1.11
2003	1.40	1.10
2004	1.37	1.03
2005	1.38	1.00
2006	1.35	0.97
2007	1.33	0.92
2008	1.30	0.87
2009	1.29	0.86
2010	1.30	0.87
2011	1.27	0.84
2012	1.30	0.88
2013	1.33	0.88

Table 4. GDP per capita

Year	Housing estates	GDP per capita: HK\$	Year	Housing estate	GDP per capita: HK\$
2007	700	233 358	2022	2015	324 072
2008	865	234 722	2023	2015	330 095
2009	1140	243 227	2024	2015	336 298
2010	1360	252 027	2025	2015	342 698
2011	1574	261 177	2026	2015	349 308
2012	1795	270 679	2027	2015	356 144
2013	2015	275 640	2028	2015	363 216
2014	2015	280 734	2029	2015	370 534
2015	2015	285 957	2030	2015	378 117
2016	2015	291 311	2031	2015	385 975
2017	2015	296 413	2032	2015	394 122
2018	2015	301 652	2033	2015	402 563
2019	2015	307 029	2034	2015	411 313
2020	2015	312 549	2035	2015	420 381
2021	2015	318 229	2036	2015	429 774

Table 6. MSW disposed and MSW recovered

Year	MSW disposed: 1000 t	MSW recovered: 1000 t
1991	2700	1560
1992	2890	1780
1993	3090	1740
1994	3080	1860
1995	2850	1930
1996	2970	1640
1997	3170	1540
1998	3190	1560
1999	3380	1540
2000	3420	1760
2001	3390	1940
2002	3440	1990
2003	3450	1960
2004	3400	2380
2005	3420	2300
2006	3390	2590
2007	3350	2840
2008	3300	2810
2009	3270	3140
2010	3330	3600
2011	3280	3020
2012	3396	2163
2013	3485	2009

domestic waste disposal rate has declined, for instance, it was 0.97 kg/d in 1991 but only 0.88 kg/d in 2013.

Table 6 lists the MSW disposed and recovered during the year 1991–2013 collected from the EPD of HK, which shows that the amount of MSW disposed and recovered has constantly been increasing from the year 1991 to 2013.

Table 7 lists the quantities of waste disposed at landfills from the year 2005 to 2013 collected from the EPD of HK. These quantities have increased since 2007. The amount of waste

Table 7. Quantities of waste disposal at landfills in 2005–2013

Quantity: 1000 t	2005	2006	2007	2008	2009	2010	2011	2012	2013
Domestic	2490	2420	2330	2230	2200	2240	2180	2301	2321
Commercial	690	750	800	830	850	860	861	827	879
Industrial	240	210	230	240	230	230	242	268	285
Construction	2390	1510	1150	1130	1140	1310	1216	1259	1311
Special	640	600	570	510	450	410	413	412	428
Total	6450	5490	5080	4940	4870	5050	4912	5067	5223

Figure 2. System-based MSW prediction and response model

disposed of declined in 2006 but increased at a rapid rate from 2007 onward and reached 5.223 Mt in 2013.

These data assisted with the determination of coefficients used in the SD modelling in Vensim 6.0 to project the future waste generation in HK. Disposal volumes were computed by MSW generation/recovery rate. The system-based prediction and response model in Figure 2 considers variables such as MSW volume rate, landfill rate for landfill capacity, MSW disposal volume, population and household spending.

Figure 3 is the tree diagram for the SD modelling, where Figure 3(a) shows the main variables used to compute the

MSW generation rate in HK; Figure 3(b) shows all consequences of landfills; and Figure 3(c) shows all consequences of MSW generation.

5.3 Simulation results and finding

Table 8 shows the sensitivity analysis on landfill recovery rates forecasting until 2025. The ‘MSW landfill volume reduced’ column shows the reduction in the landfill volume, which shows a positive sign that there is a decline in the landfill through the use of prevention methods by the government.

The simulation compares the forecasting of MSW generation and the total waste generation in HK until 2025, in which

Figure 3. Tree diagrams for MSW in HK: (a) main variables used to compute the MSW generation rate in HK, (b) all consequences of landfills and (c) all consequences of MSW generation

Table 8. Simulation on landfill recovery rate

Year	Total waste generated per day: t	Annual landfill rate: 1000 t	Landfill prevention with measures: 1000 t	Total waste landfill volume reduced: 1000 t
2013	14 311	5 151 960	3 245 735	1 906 225
2014	14 798	5 327 280	3 356 186	1 971 094
2015	15 301	5 508 360	3 470 267	2 038 093
2016	15 821	5 695 560	3 588 203	2 107 357
2017	16 359	5 889 240	3 710 221	2 179 019
2018	16 915	6 089 400	3 836 322	2 253 078
2019	17 490	6 296 400	3 966 732	2 329 668
2020	18 085	6 510 600	4 101 678	2 408 922
2021	18 700	6 732 000	4 241 160	2 490 840
2022	19 335	6 960 600	4 385 178	2 575 422
2023	19 993	7 197 480	4 534 412	2 663 068
2024	20 673	7 442 280	4 688 636	2 753 644
2025	20 802	7 488 720	4 792 781	2 770 826

MSW is constantly increasing but there is a slow decline in the growth of the MSW generation. Table 9 forecasts MSW generation and recycling until 2025 based on the simulation. The main reason for the higher increase from the year 2013 to 2022

is that the three remaining landfills will close between 2017 and 2019. After 2019, there will be no landfill available to dispose of MSW, which will lead to waste overflow in 2020. However, the HK government has identified this

Table 9. Simulation on waste generation and recycled

Time: year	Total waste generation: Mt	MSW generation: Mt	MSW recycled: Mt
2013	5.152	3.437	1.272
2014	5.327	3.554	1.315
2015	5.508	3.675	1.360
2016	5.696	3.800	1.406
2017	5.889	3.929	1.454
2018	6.089	4.062	1.503
2019	6.296	4.200	1.554
2020	6.511	4.343	1.737
2021	6.732	4.461	1.784
2022	6.914	4.581	1.832
2023	7.100	4.705	1.882
2024	7.292	4.832	1.933
2025	7.489	4.962	1.985

issue and is developing new landfills as a solution. The total waste generation in 2013 was 5.152 Mt, and the MSW generation was 9547 t/d so that the annual MSW generation is $9547 \text{ t} \times 12 \times 30 = 3.437 \text{ Mt/year}$. MSW in 2013 was 3.437 Mt/year but increasing at a rapid pace due to the fast growth of population. Table 10 lists the historical data of MSW disposed at landfills from 2007 to 2013; this shows a fluctuation in the domestic solid waste from 2008, but it started to increase from 2011 to 2.321 Mt in 2013. The commercial solid waste disposal at landfills has also increased from 2007 to 2013. There is a general increase in the quantities of all types of solid waste disposed at the landfills from the year 2007 to 2013. The left graph in Figure 4 simulates the MSW recycled from the year 2013 to 2025 and showed that the recycling rate will increase in the near future. The middle graph in Figure 4 simulates the landfilled waste in HK. The right graph in Figure 4 shows the amount of waste prevented from going to landfill, which shows a similar, positive trend.

Figure 5 simulates the comparison among total waste generation, MSW generation and waste recycled until the year 2025. The amount of landfilled waste is below the level of MSW generation. The amount of landfilled waste is increasing over the coming decades. The high recycling rates may be due to the closure of landfills that are currently operating, forcing

more waste to be effectively recycled with more advanced disposal techniques.

5.4 Comparative discussions between HK, Singapore and Shanghai

Semi-structured interviews were conducted with officers in the EPD of HK, Shanghai Environmental Protection Agency and the National Environmental Agency Singapore and related documentation was carefully studied. The fast economic and population growth in HK and Singapore have led to significant increases in MSW generation in both cities, leading to an increased environmental burden in relation to water, air and soil pollution, natural habitat degradation and various diseases. HK and Singapore are the most developed cities, major commercial hubs and financial centres in the Southeast Asia. Both are small but highly populated; Singapore is smaller than HK but has a greater population. Singapore has an annual MSW generation around 7 Mt equivalent to 1.3 (t/capita)/year. The waste management policy in Singapore was developed by the National Environmental Agency Singapore, guided by three major policy platforms relating to waste minimisation, recycling at landfills and waste reduction through incineration. The total amount and proportion of MSW generation in HK and Singapore is very similar, but Singapore has a better MSW recovery and recycling rate than HK. The collection and disposal of industrial and commercial wastes in Singapore are paid for by commercial organisations instead of individuals, and this stimulates waste recycling. Currently, about 2000 t of waste in Singapore is transported daily from the Tuas Marine station to the landfill. The landfill covers 350 ha, and it has been effectively managed to run for a long period. Singapore has a better landfill management and MSW processes than HK does.

Shanghai is the largest and most highly populated port city in the mainland China with an around 25 million population (An *et al.*, 2014). Similar to HK and Singapore, Shanghai is also a global financial centre and a transport hub that has experienced rapid growth, urbanisation and industrialisation, all of which has generated significant increases in MSW (Gao, 2008). Shanghai has around 7.02 Mt waste per year of which 52% was disposed in landfills, 10% was composted, 16% was

Table 10. Quantities of solid waste disposed of at landfills in 2007–2013

Quantity: Mt	2007	2008	2009	2010	2011	2012	2013
Domestic	2330	2230	2200	2240	2180	2301	2321
Commercial	800	830	850	860	861	827	879
Industrial	230	240	230	230	242	268	285
Construction	1150	1130	1140	1310	1216	1259	1311
Special	570	510	450	410	413	412	428
Total	5080	4940	4870	5050	4912	5067	5223

Figure 4. MSW recycled (top), landfilled waste (middle) and prevented from landfill (bottom)

incinerated and 19% discarded at unsanitary landfills (Chung *et al.*, 2010). The investment in waste processing and the construction of sewage treatment plants and sewer networks has been steadily improving in Shanghai (Chung *et al.*, 2010).

Shanghai has about 30 small-to-medium-sized sewage treatment plants and three large sewage treatment plants ('Laogang', 'HK Bailong' and 'Chuk Yuen') handling up to 170 t of waste daily (Zhang *et al.*, 2012). Also, to improve the wastewater collection and treatment, 659 km of the pipeline has been newly laid. However, despite the good infrastructure, it seems some treatment plants are not connected to the sewerage system. While this kind of issue has certainly drawn great attention, it is subordinate to economic needs (Zhang *et al.*, 2012). Shanghai has less MSW generation than HK over the last decades due to the more effective planning measures and government policies that have been enacted.

Among these three cities, HK has the highest MSW generation rates due to the less effective planning measures and government policies. Based on the interviews, some recommendations for HK were derived according to the experiences of Singapore and Shanghai in dealing with MSW generation. Singapore has implemented a national recycling programme, which is a voluntary programme for households as well as for trade premises. Under the national recycling programme, bags and bins are provided for waste storage, and these bags and bins are collected fortnightly; around 63% Singapore households participated in this programme. Apart from the MSW collection, Singapore has also implemented the waste minimisation hierarchy 'Towards Zero Landfill'. The main goal of the programme was to move the city towards zero landfill use by reducing waste generation. Payments received from commercial organisations, rather than individuals in Singapore, has played an important role in waste processing. Singapore also has the effective 'Recycling Corner Programme' that started in 2002 for schools to provide education and consultation to students about reducing, reusing and recycling waste; around 84% Singapore schools joined this programme, and it plays an important role in shaping the behaviours of future generations (Williams, 2014). HK could also implement the strategies learnt from Shanghai; for example, one useful strategy developed by the Environment Protection Agency Shanghai was to allocate special funds for waste management. Shanghai every year allots around US\$5 billion (3.05% of the city GDP) for this purpose (Yang *et al.*, 2014). The government of Shanghai charges US\$0.44 per month to each household for waste manage services.

6. Conclusion

Historical data regarding MSW generation in HK (including MSW volume rate, landfill rate for landfill capacity, MSW disposal volume, population and household spending) were used to determine coefficients in the SD modelling to project the future waste generation in HK. A system-based MSW prediction and response model was developed in this study using a seven-step SD model. The SD simulation forecasts the MSW

Figure 5. Comparison among waste generated, recycled, landfilled and landfilled recycled

generation and recycling in HK, which shows that in the near future the MSW will increase based on the current growth rates, and along with that the waste recycling will also improve. The strategies developed by the HK government regarding MSW disposal provide scope for further improvement because HK will experience more severe MSW conditions in the future as its landfills are expected to be closed earlier than planned. Compared with Singapore and Shanghai, HK has a higher MSW generation rate due to less effective planning measures and government policies. Recommendations for HK to support the management of MSW generation were derived according to the experiences of Singapore and Shanghai. HK could learn from Singapore and start programmes to provide education and consultation to school students on reducing, reusing and recycling of waste to shape and influence the behaviours of future generations. HK could also implement the strategies learnt from Shanghai to allocate special funds for waste management. Future studies are recommended to simulate the MSW generation and recycling in all these cities so that accurate comparison can be made that will allow the development of an effective solution for HK as well as the other two cities.

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