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Comparative analysis of solid waste management in 20 cities

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Abstract

This paper uses the 'lens' of integrated and sustainable waste management (ISWM) to analyse the new data set compiled on 20 cities in six continents for the UN-Habitat flagship publication *Solid Waste Management in the World's Cities*. The comparative analysis looks first at waste generation rates and waste composition data. A process flow diagram is prepared for each city, as a powerful tool for representing the solid waste system as a whole in a comprehensive but concise way. Benchmark indicators are presented and compared for the three key physical components/drivers: public health and collection; environment and disposal; and resource recovery – and for three governance strategies required to deliver a well-functioning ISWM system: inclusivity; financial sustainability; and sound institutions and pro-active policies. Key insights include the variety and diversity of successful models – there is no 'one size fits all'; the necessity of good, reliable data; the importance of focusing on governance as well as technology; and the need to build on the existing strengths of the city. An example of the latter is the critical role of the informal sector in the cities in many developing countries: it not only delivers recycling rates that are comparable with modern Western systems, but also saves the city authorities millions of dollars in avoided waste collection and disposal costs. This provides the opportunity for win–win solutions, so long as the related wider challenges can be addressed.

Keywords

Integrated sustainable waste management, solid waste management, cities, comparative analysis, governance, technologies, benchmark indicators, informal sector

Introduction

This paper is based on work carried out to prepare UN-Habitat's Third Global Report on Water and Sanitation in the World Cities *Solid Waste Management in the World's Cities*, which was launched at the 'Fifth World Urban Forum' in Rio on 23 March 2010 and which subsequently won the 2010 ISWA Publication Award (Scheinberg et al., 2010b). This was the first time in more than 10 years that the UN system has focused on solid wastes.

The book was the product of a combined effort of more than 35 professionals on solid waste from economically developing, transitional, and developed countries, many of whom are connected through the CWG (Collaborative Working Group on Solid Waste Management in Low- and Middle-Income Countries), a global community of practice. The work was co-ordinated by WASTE, an institute-type nongovernmental organization (NGO) in the Netherlands, which specializes in multi-country research and development programmes.

In conceiving the work, Habitat was seeking to produce a definitive guidance document based on the combined experiences that the team members had accrued over the past 40 years. That alone could have produced a valuable reference work, but the authors-editors had even higher ambitions: to address one of the major constraints in comparing solid waste management systems in different cities and countries, the lack of reliable and consistent data. The basic kinds of information are collected in very different ways in each city, if indeed they are collected and recorded at all. Not even the most basic indicator, cost per ton, is available for most cities.

So the team took up the challenge of looking into the present situation and collecting new data for 20 'representative', reference cities around the world, in order to tap into realities of what solid waste management currently is, and what it can mean for cities, whether they are located in low-, middle- or high-income countries. The tight timeframe for publishing the book meant that, while the data was presented and used to support the discussion and influence the conclusions, there was little time to analyse it.

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This paper presents the results of a subsequent comparative analysis of the 20 cities, using the fresh and exciting data collected for the UN-Habitat project to compare and contrast solid waste management systems in cities around the world. This is important to allow cities to learn from each other, and also to draw out global best practice guidance.

Methodology

Analytical framework

The analytical framework is built around the concept of integrated and sustainable (solid) waste management, known as ISWM (IJgosse et al., 2004; Schübeler, 1996; Van de Klundert and Anschütz, 2001). The ISWM framework distinguishes three dimensions for analysis of solid waste management and recycling systems: the physical system and its technological components, sustainability aspects (social, institutional, political, financial, economic, environmental and technical) and the various groups of stakeholders involved. The global team responsible for the book divided an ISWM system for analytical purposes into two 'triangles', the physical components and the governance features (Scheinberg et al., 2010b). The first 'triangle' focuses on three key drivers for development of waste management (Wilson, 2007), corresponding to the three key physical, 'hardware', components:

- Public health: maintaining healthy conditions in cities through a good waste collection service.
- Environment: protection of the environment throughout the waste chain, especially during waste treatment and disposal.
- Resource management: 'closing the loop' and returning both materials and nutrients to beneficial use, through preventing waste and striving for high rates of reuse, materials recycling and organics recovery.

Historically, the public health driver first emerged during industrialization and the first wave urbanization, and the environmental driver appeared and began to influence waste management systems in the 1970s. The resource management driver both predates and follows the other two in developmental processes in cities (Scheinberg, 2011; Velis et al., 2009; Wilson, 2007). A useful point of comparison with the status today is provided by a comparative review of official statistics on municipal solid waste management (MSWM) in the then 12 member states of the European Union in 1990, carried out by one of the authors for the European Commission (ERL, 1992).

The second 'triangle' focuses on ISWM 'software': the governance strategies to deliver a well-functioning system. When solid waste systems fail, the observation of the group of 35 professionals working on the original Habitat project is that they seldom do so for technical reasons, but because of politics, economics, or institutions. Therefore three inter-related requirements for delivering ISWM under the framework of 'good waste governance' have been identified:

- *Inclusivity*: providing transparent spaces for stakeholders to contribute as users, providers and enablers.
- *Financial sustainability*: being cost-effective and affordable.
- A base of *sound institutions and pro-active policies*.

Data collection and comparison

In order to make comparison possible among very different cities from all over the world, a detailed methodology was prepared, which took several hundreds of hours of discussions to design and over 40 pages of instructions to describe. This sought information on some 300 separate characteristics, both quantitative and qualitative, covering both general and specific waste data, the physical components of the system and the governance aspects.

For each city, a contact person was designated – the city profiler – who has lived and/or worked in the city and knows its situation well. That person functioned both as the lead researcher, but also as a point of contact with the city authorities, who of course provided most of the data based on their own records. The appointed city profilers came from different professional backgrounds – including consultants, scientific researchers, public servants and advocacy NGO workers. This provided a variety of inputs and perspectives that enriched the book. At the same time, it meant that it was essential that the language, definitions and metrics be shared and understood in the same way within the team so as to ensure meaningful comparison among cities.

This detailed information on each city was used to prepare a standardized city profile of around 15–25 pages. This was designed to present the key indicators and the key narratives about the waste management policies and practices in the cities, in a form that was both accessible to readers and easy to compare between cities.

In order to facilitate comparison between cities and to support a discussion of global best practices, the original project team set out to generate a series of *benchmark indicators* that can be applied to cities in low-, middle- and high-income countries. Benchmarking of waste management services is far from a straightforward exercise; even within a single small country with uniform regulations, level of development, culture, governance system, and climatic conditions, as 12 years of benchmarking experience in the Netherlands confirm (Mvulirwenande and Rodic, 2012).

From the 300 characteristics reported in the city profile, the team selected a basic set of seven benchmark indicators to cover the three drivers/physical components and the three governance strategies of an integrated sustainable waste management system. The definition of the benchmark indicators is shown in Table 1. Four of these were quantitative indicators, whereas three, relating to the non-financial governance strategies, were qualitative. However, as is emphasized later in the discussion, this set of benchmark indicators is of necessity a simplification, and a full comparison needs to delve much more deeply into the full set of 300 system characteristics included in the city profiles.

Table 1. Definition of benchmark indicators

No	Analytical criteria	Indicator	Description
	Drivers for SWM		
1	Public health	Waste collection and sweeping coverage	Quantitative percentage of citizens who have access to a reliable waste collection service.
2	Environmental control	Controlled disposal	Quantitative percentage of the total waste destined for disposal which goes to an engineered landfill, a controlled disposal site or any type of controlled treatment, including thermal treatment.
3	Resource management	Materials recycled or recovered (valorized)	Quantitative percentage of total waste which is recycled as materials – the term 'valorization' is used to indicate that both recycling of dry materials (glass, metals, paper, plastics, etc.) and various forms of organics recovery (composting, anaerobic digestion, animal feeding) are included.
	Governance strategies		
4A	User inclusivity	Degree of user inclusivity	Composite score on a set of quality indicators allowing a yes for present and a no for absent. Represents the degree to which users of the solid waste services (i.e. households, business and other waste generators) are included in the planning, policy formation, implementation and evaluation of those services. The indicators are: 1. laws at national or local level that require consultation and participation with stakeholders outside the bureaucratic structures; 2. procedures in place/ evidence of citizen participation in the siting of landfills or other treatment facilities; 3. customer satisfaction in the waste management services being measured at the municipal level; 4. feedback mechanisms between service users and service providers; 5. citizens committees in place that address WM issues.
4B	Provider inclusivity	Degree of provider inclusivity	Composite score on a set of quality indicators allowing a yes for present and a no for absent. Represents the degree to which non-municipal waste service providers from the formal private, community or informal sectors are included in the planning and implementation of solid waste and recycling services and activities. The indicators are: 1. laws at national or local level in place which encourage public–private partnership (PPP), private sector participation (PSP) or community based organisation (CBO) participation; 2. organisations or platforms in place which represent the private waste sector (formal, community-based or informal); 3. evidence of formal occupational recognition of the informal sector active in WM practices or recycling; 4. evidence of protection of informal sector rights to operate in WM; 5. little or no institutional or legal barriers for PSP in WM in place; 6. institutional or legal incentives for PSP in WM in place.
5	Financial sustainability	Population using and paying for collection	Quantitative percentage of total households both using and paying for waste collection services.
6	Institutional coherence	Degree of institutional coherence	Composite score on a set of quality indicators. The first four indicators assess policy and the degree of municipal control. 1. Are there any sustained policy commitments to sustainable solid waste management? 2. Is there a clear and transparent policy framework for the planning and implementation of waste management practices? 3. Are authorities allowed to retain the revenues collected from the municipal fines and charges or to levy direct charges for services? 4. Are the out-sourced municipal waste collection services defined, supervised and controlled by the municipalities? The remaining two indicators assess the degree to which the solid waste budget is directly controlled by one responsible department within the city, and the degree of management control over WM which that department has (based on a qualitative assessment of the organizational chart of the city).

Note: the qualitative indicators (4A, 4B and 6) are first scored on a percentage basis (e.g. 20% for a 'yes' where there are five indicators or 16.67% where there are six indicators), and then translated into a 'HIGH' (71% and over), 'MEDIUM/HIGH' (61–70%), 'MEDIUM' (35–60%) or LOW (33% or below) rating.

Figure 1. Map showing the location of the 20 reference cities.

Selection of the reference cities

In parallel with the development of the profiling methodology, two sets of criteria were established for selection of the reference cities to be included in the project. The first set was applied to the overall choice of cities, which were chosen to include:

- a range of sizes, from mega-city to small regional city;
- a range of geographic, climatic, economic and political conditions;
- cities from high-, middle- and low-income countries;
- a majority of cities from low- and middle-income countries;
- at least one city from each inhabited continent.

The second set of criteria was applied to the selection of the individual cities. Any city selected:

- gives a good illustration of one or more points of interest;
- has an administration and other stakeholders willing to participate, prepare the materials, provide information and share both good and not-so-good experiences;
- has a connection to the book's author group or UN-Habitat, so that a suitable city-profiler is available.

The selected reference cities are shown on the map in Figure 1 and some comparative data are presented for them in Table 2.

Geographically, the reference cities are situated in all six continents, and range from the city of Rotterdam at 52°N to Adelaide at 35°S. The cities cover a wide range of population and situations, from India's capital mega-city of Delhi with an official population approaching 14 million, to the small regional centre of Canete in Peru, with population around 50 000; or from the 4 million capital city of Nairobi, Kenya, situated on the equator, to a small university centre of Ithaca of 30 000 inhabitants in Tompkins County in New York State, USA.

Comparing the cities

For comparative analysis and discussion, it was decided to follow common practice and to classify countries according to income per capita (gross national income or GNI capita^{-1}), using the World Bank's grouping into low, lower middle, upper middle and high income countries (World Bank, 2010). There are at least four cities in each of the four income categories, with six each in the two lower income categories – which is roughly in line with the spread of income between countries.

UNDP's human development index (HDI) is also reported; this measures the average achievements in a country in three basic dimensions of human development: a long and healthy life, knowledge and a decent standard of living (UNDP, 2009). A scatterplot of GNI capita^{-1} against HDI indicates a positive correlation, with the GNI capita^{-1} increasing exponentially with the increase of HDI. For the dataset of cities considered here, HDI is normally distributed, whereas gross domestic income (GDI) capita^{-1} is not – the latter is clustered in two groups, US$0–7000 and US$39 000–47 000 (Table 2). Hence, HDI provides a better basis for linear regression analysis with other explanatory variables: given their exponential relationship, similar explanations can be reached by using log-transformed GNI capita^{-1} values.

Regression analysis was performed to the available variables (Statistica® v10), to reveal interdependencies. The following are reported where appropriate: the Pearson's linear product–moment correlation coefficient (r), determining how proportionate to each other is the change of the variables; the adjusted squared coefficient of determination (R_{adj}^2), denoting how much of the variability in the dependent variable can be explained by the independent; and the p-value, which can be compared against any set level of significance (α). In order to be robust to outliers and skewed distributions, non-parametric statistics (median, inter-quartile range) were used for reporting category averages and data spread. Suitable diagrams (scatterplots,

Table 2. The Reference Cities (Source: Scheinberg et al., 2010)

City	Country	Continent	Country characteristics				City characteristics				
			Income category[1]	GNI capita^{-1}	HDI[2]	Population[3]	Area (km^2)	Population density[3] (no km^{-2})	Population growth rate[3] (%)	National (N) or Regional (R) capital	Coastal (C) or Island (I) location
Rotterdam	Netherlands	Europe	High	48 460	0.964	582 949	206	2831	–0.2		C
San Francisco	USA	N. America	High	46 360	0.956	835 364	122	847	1.0	R	C
Tompkins County	USA	N. America	High	46 360	0.956	101 136	1272	80	0.1		
Adelaide	Australia	Australia	High	43 770	0.970	1 089 728	842	1295	1.0	R	C
Belo Horizonte	Brazil	S. America	Upper-middle	8040	0.813	2 452 617	331	7411	1.2	R	
Curepipe	Mauritius	Africa	Upper-middle	7250	0.804	83 750	24	3534	0.8		I
Varna	Bulgaria	Europe	Upper-middle	6060	0.840	313 983	80	3925	–0.1	R	C
Canete	Peru	S. America	Upper-middle	4200	0.806	48 892	512	95	2.7		
Sousse	Tunisia	Africa	Lower-middle	3720	0.769	173 047	45	3845	3.3	R	C
Kunming	China	Asia	Lower-middle	3650	0.772	3 500 000	2080	1683	1.0	R	C - lake
Quezon City	Philippines	Asia	Lower-middle	2050	0.751	2 861 091	161	17 758	2.9		I
Bengaluru	India	Asia	Lower-middle	1180	0.612	7 800 000	800	9750	2.8	R	
Delhi	India	Asia	Lower-middle	1180	0.612	13 850 507	1483	9340	1.5	N	
Managua	Nicaragua	C. America	Lower-middle	1000	0.699	1 002 882	289	3470	1.7	N	C - lake
Lusaka	Zambia	Africa	Low	970	0.481	1 500 000	375	4000	3.7	N	
Nairobi	Kenya	Africa	Low	760	0.541	4 000 000	696	5746	4.5	N	
Bamako	Mali	Africa	Low	680	0.371	1 809 106	267	6776	4.8	N	
Dhaka	Bangladesh	Asia	Low	580	0.543	7 000 000	365	19 178	1.7	N	
Moshi	Tanzania	Africa	Low	500	0.530	183 520	58	3164	2.8		
Ghorahi	Nepal	Asia	Low	440	0.553	59 156	74	795	4.0		

Notes:
[1]The division of countries into income categories follows the World Bank's main criterion for classifying economies, which uses the gross national income (GNI) capita^{-1}. (Prior to 2010 GNI was referred to as gross national product, or GNP.) The groups based on GNI capita^{-1} at 2009 levels are: low income, US$995 or less; lower-middle income, US$996 – US$3945; upper-middle income, US$3946 – US$12 195; and high income, US$12 196 or more (World Bank, 2010).
[2]HDI is the human development index, a composite measure including a long and healthy life, knowledge and a decent standard of living. Data are from the UNDP 2009 Human Development Report (UNDP, 2009) and apply to 2007.
[3]Population data are the latest available for each city – in most cases they apply to 2006. Bamako data are from the 2009 census.

box-plots, etc.) were employed to summarize data and illustrate key findings.

In this paper, both tabular and statistical reporting of the data are used:

- All of the benchmark indicators for each of the 20 reference cities are tabulated. Otherwise, for reasons of space, summary tables are presented, showing average (arithmetic mean) data for the cities grouped by national income. Full comparative tables for all the cities are available elsewhere (Scheinberg et al., 2010b; Wilson et al., 2010).
- The tabular reporting is complemented by very selective results from the statistical analysis, chosen both to show interesting results and to illustrate what could be done with a larger dataset; the current regression results are limited by the number of cities available (20 or less), which makes compliance with the underlying assumptions more important than for instance if 50 cases were available. Hopefully it will be possible to repeat the analysis when data for more cities become available.

Process flow diagrams

The core of the data collection and analysis method used a process flow diagram (PFD) to represent a city's solid waste and recycling system – including both formal and informal elements and operations. As previously demonstrated (Brunner and Fellner, 2007; Scheinberg et al., 2010a), PFD is a relatively powerful way of presenting the system as a whole in a comprehensive but concise way.

A PFD is a form of materials flow analysis, and has the advantage that it gives a total graphic picture of a solid waste system at a glance, based on process steps and the movement of material streams between them. This implies several distinct advantages: all the waste streams are accounted for, leaks and losses are exposed, system boundaries are clearly denoted, no activities are forgotten and final destinations of waste materials are explicit. In addition, the place and contributions of all stakeholders are visible, as are the linkages and transactions between them. All of this is helpful in identifying possible points for interventions aimed at improving the integrated operation of the overall waste management system (Rodic et al., 2010).

The PFD is an especially useful tool to represent complex solid waste management systems that are characterized by services provided in parallel by competing service providers, or by a high degree of mixing of formal and informal sectors, and mixing of public and private service providers. For example, a PFD enables accurate representation of situations common in some of the reference cities, for example where waste is officially destined for and reaches a disposal site but is picked over there by informal waste pickers and the recyclable materials returned to the industrial value chain; or where the waste is dumped illegally, possibly picked over to remove recyclables, grazed over by animals, with the residue then being removed by the city and taken to the official disposal site. Where the reality may involve double-passage of waste through certain steps, a PFD presentation can show this, whereas a more traditional, tabular presentation would include these amounts either under official disposal or under recycling or under illegal disposal, thus losing both valuable information and insight into how the system actually works; entering a number twice would upset the mass balance through double counting.

The informal sector is referred to regularly in this paper. The definition used here is that from a 2006 GTZ study: "The 'informal solid waste sector' refers to individuals or enterprises who are involved in recycling and waste management activities but are not sponsored, financed, recognised or allowed by the formal solid waste authorities, or who operate in violation of or in competition with formal authorities" (Scheinberg et al., 2010a; 2011; Wehenpohl et al., 2007). It is important to note that many informal waste and recycling businesses are registered to work as transport, construction, cleaning or agricultural enterprises, or even as businesses in the industrial value chain, and in those sectors they do pay taxes. The definition of informality relates to their lack of recognized status within the solid waste sector.

Comparing wastes and flows

Waste generation

The first comparison is between the relative quantities of waste generated per capita in the 20 cities. Even this apparently simple comparison posed considerable challenges – definitions of 'municipal solid waste' vary widely between countries, including varying proportions of their commercial, industrial and construction and demolition (C&D) wastes. The data used in the scatterplots in Figure 2 and to calculate the averages shown in Table 3 have been corrected to remove some of the more obvious discrepancies – such as the reported data for Adelaide and Belo Horizonte, which appeared to include a much larger proportion of C&D wastes than in other city definitions.

The data in Figure 2 and Table 3 show that per capita waste generation increases with both the development level (HDI) and the income level (GNI capita^{-1}) of the country, although the differences between income levels are less marked than in previous studies (see for example Chalmin and Gaillochet, 2010; Hoornweg and Thomas, 1999). This is a clear trend, despite the wide variation between individual cities, as shown in both the scatterplots and by the overlapping ranges in the table. It is noted that Belo Horizonte in Brazil and Managua in Nicaragua (the top of the range for upper- and lower- middle-income countries respectively) have relatively high generation rates for their income group, which may be a general characteristic of Latin America. The relatively high figure for Moshi in Tanzania (top of the range for low-income countries) raises a question as to whether the data have been averaged to even out seasonal variations, which are particularly important outside of the high-income countries and where the availability of local fruit and

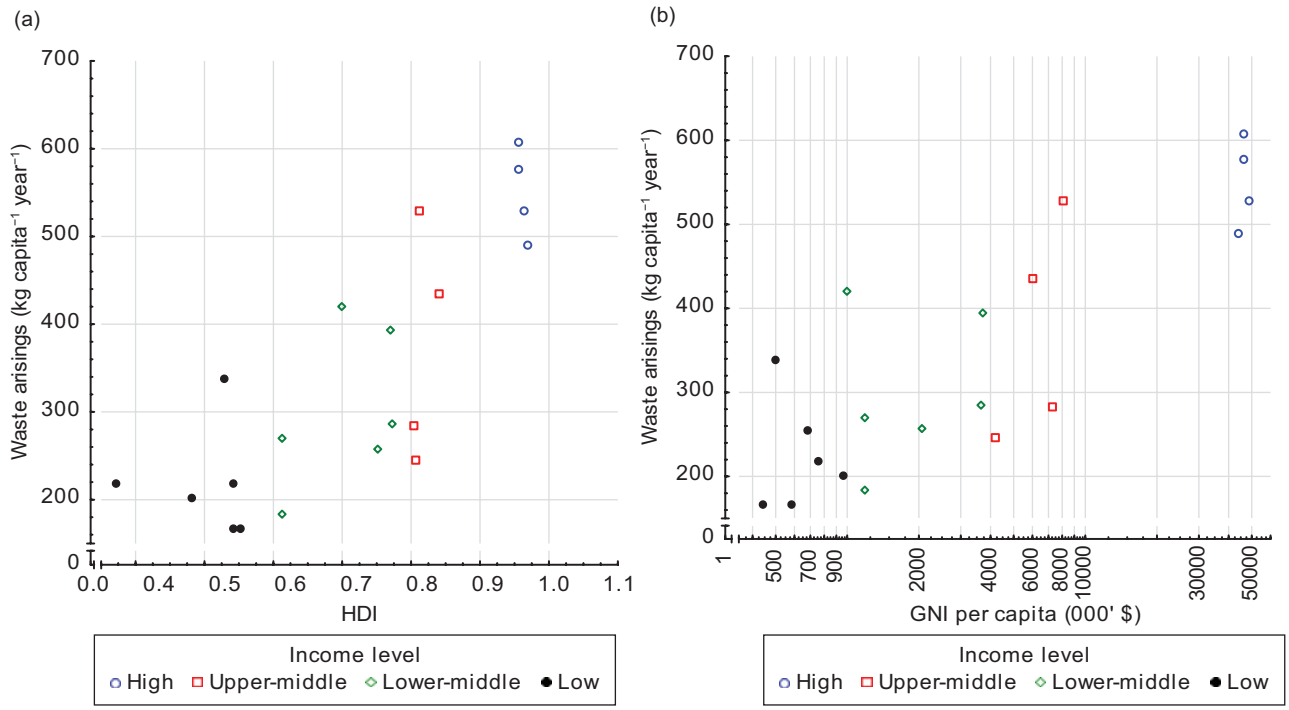

Figure 2. Scatterplot of waste generation per capita against (a) the human development index (HDI); and (b) gross national income (GNI) per capita on a logarithmic scale. Regression suggests a positive linear correlation with the HDI, which is capable of explaining 60% of the variability in waste arising ($r = 0.79$, $p < 0.00004$, $R_{adj}^2 = 0.60$), and on a logarithmic scale with GNI capita^{-1} ($r = 0.79$, $p < 0.00003$, $R_{adj}^2 = 0.60$). A linear correlation is used for HDI, as the city data for HDI is more normally distributed, whereas GNI capita^{-1} data are clustered in two groups, giving an exponential distribution when plotted against HDI.

Table 3. Per capita waste generation

Income level	Minimum (kg year^{-1})	Maximum (kg year^{-1})	Average (kg year^{-1})	Average (kg day^{-1})
High	490	609	551	1.51
Upper-middle	246	529	373	1.02
Lower-middle	184	420	302	0.83
Low	167	338	219	0.60

vegetables is still seasonal – for example, the availability of plantains in East Africa, coconuts in the Indian sub-continent or water melons in China (Chung and Poon, 2001) and many other countries significantly increases the per capita waste generation figures.

Waste composition

Figure 3 provides comparative data on waste composition for the four income groups. These data need to be treated with some caution for at least three reasons:

1. The definition of what waste materials are included in municipal solid waste affects composition – for example, Adelaide has a high value for 'other' which again reflects the large fraction of C&D wastes.
2. Many of the lower-income cities have data on waste composition which is more than 10 years old and may not adequately reflect current consumption patterns, for example, consumption of plastic packaging and electronic equipment.
3. Cities differ widely as to how and where in the system composition is measured. The measurements may apply to: (i) the whole waste stream *generated*; (ii) the wastes *collected* from households; or (iii) the wastes arriving at the *disposal* site. For example, when an active informal sector is removing waste for recycling at different points of the system, the result is that waste composition figures may be measured after some recycling has already happened, so comparisons can be misleading. City authorities are often unaware of these nuances.

Despite these caveats, some interesting comparisons can be made:

- Paper percentages appear relatively low outside of the high-income countries. The detailed data show 14 cities reporting 3–10%, with only four cities reporting more than 15%, in Mauritius (upper-middle-income), Netherlands and the USA – their average is 27%.

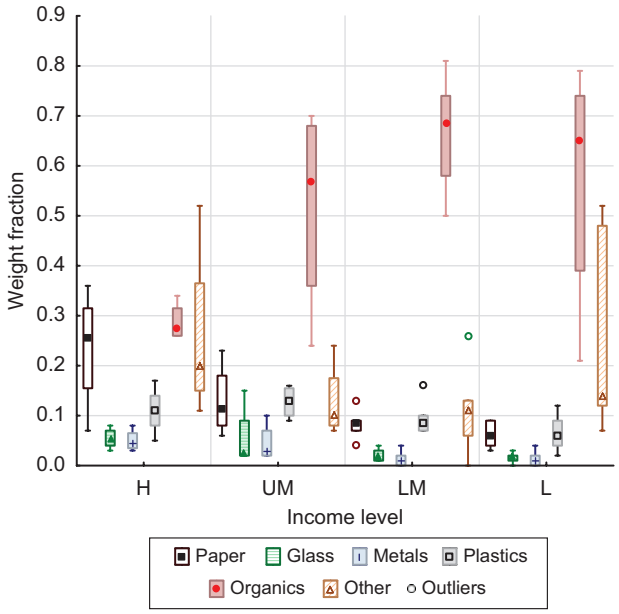

Figure 3. Boxplots of key waste MSW components (paper, glass, metals, plastics, organics, and other), for each of the four income categories. Key to income categories: H: high; UM: upper-middle; LM: lower-middle; L: low. Median value is within the box, and the box demonstrates the inter-quartile range (Q1–Q3), i.e., 25% above and below the median level. A clear trend is evident for higher Organics at lower income level. The median Organics level is almost 70% for the lower-middle income cities. The slightly lower median level for the low-income cities is due to unexpectedly low values reported for Bamako and Lusaka (24 and 39% wt., respectively), where a high 'other' (ca. 50% wt.) component is also reported – this could be due to high amounts of sand and grit being swept, and/or to methodological problems in accurately capturing the waste composition). If Bamako and Lusaka are excluded, the median Organics for the low-income cities rises to 70% wt. Metal, paper and glass show the opposite behaviour. Metals correlate positively with glass ($r = 0.80$, $p < 0.0001$, $R_{adj}^2 = 0.62$), and negatively with organics ($r = 0.78$, $p < 0.0001$, $R_{adj}^2 = 0.58$).

- Glass and metals are both relatively low, with 16 of the cities in the range 0–4% for both. Three of the high-income cities report slightly more (maximum 8%), while Varna in Bulgaria appears to be an outlier (15% glass and 10% metal).
- Plastic levels appear generally higher, but do not show the perhaps expected increase with income level. Just two cities report less than 5%, 10 cities are in the range 5–10% and eight are between 11 and 17%. Rotterdam reports the highest figures (17%), but those for Curepipe, Mauritius (16%), Quezon City, Philippines (16%), and Nairobi, Kenya (12%), are unexpectedly higher than for both the US cities (11%).
- Organic levels generally follow expectations, with the five cities in Europe, North America and Australia (i.e. the four high-income cities plus Varna in Bulgaria) reporting 24–34% (average 28%) and 13 of the 15 'Southern' middle- and low-income countries within the range 48–81% (average 67%). This reflects both the lower consumption of seasonal fresh fruit and vegetables and the higher prevalence of packaging and other consumer products that end up in the waste stream in high income countries.

It is not possible to report waste density, moisture content or heating values, as the data are not generally available. However, the high organic content in medium- and low-income cities generally means very dense waste, high moisture content and reduced heating values, as opposed to relatively light waste with low organic content in the high-income or European countries. These differences alone are enough to raise a fundamental question, as to whether certain technologies for modern waste management developed over the last 40 years in the 'North' are indeed appropriate for export to the rest of the world. Specifically, compactor trucks designed for light 'Northern' waste with a high content of voluminous packaging materials are both unnecessary and inappropriate in many developing countries. High organic content may suggest that valorizing (recovering organic waste) should be seen as the 'baseline' technology rather than landfill disposal. A combination of high organic content, and often high tropical rainfall, which increases the moisture content even further, should advise against thermal treatment of unprocessed MSW that would require additional fuel to support combustion.

Comparing drivers/physical elements of the system

Benchmark indicators and an example process flow diagram

Table 4 shows the seven selected benchmark indicators, for all 20 reference cities. These are used to discuss in this section the three drivers/physical elements, and in the next the three governance elements of an integrated sustainable waste management system.

Figure 4 shows an example process flow diagram (PFD) for Managua in Nicaragua (Olley et al., 2010). This provides a graphic overview of the city's solid waste system, based on the physical process steps and the movement of material streams between them; it shows the activities of both the formal and informal systems, and how they have become partially integrated in the modernization process; in this case, it also provides a full mass balance.

Public health – collection coverage in the cities

Data on the coverage of waste collection and street sweeping in each city – namely the percentage of population that has access to waste collection services – is presented as indicator 1 in Table 4 and also as a scatterplot in Figure 5. These numbers matter, as there is strong evidence linking uncollected household wastes to public health, both directly to higher incidence of diarrhoea and acute respiratory infections in children (UN-Habitat, 2008), and indirectly to flooding and the spread of water-borne diseases via blocked drains.

The data show higher collection coverage than might have been expected – the World Bank website is still stating in January

Table 4. Benchmark indicators in the reference cities (Source: Scheinberg et al., 2010)

	Drivers for solid waste management			Governance strategies			
	Public health	Environmental control	Resource management	Inclusivity		Financial sustainability	Sound institutions
	1	2	3	4A	4B	5	6
City, country	Percentage collection coverage(%)	Percentage controlled disposal (%)	Percentage materials recycled or recovered (valorized) (%)	Degree of user-inclusivity	Degree of provider-inclusivity	Population using and paying for collection as percentage of total population (%)	Degree of institutional coherence
Rotterdam, Netherlands	100	100	30	HIGH	LOW	100	HIGH
San Francisco, USA	100	100	72	HIGH	LOW	100	HIGH
Tompkins County, USA	100	100	60	HIGH	MEDIUM	95	HIGH
Adelaide, Australia	100	100	54	HIGH	MEDIUM/HIGH	100	HIGH
Average for high-income	*100*	*100*	*54*	*HIGH*	*MEDIUM*	*99*	*HIGH*
Belo Horizonte, Brazil	85	100	1.5	HIGH	MEDIUM/HIGH	85	HIGH
Curepipe, Mauritius	100	100	N.A.	LOW	LOW	0	HIGH
Varna, Bulgaria	100	99	27	LOW	LOW	100	HIGH
Canete, Peru	71	81	12	MEDIUM	MEDIUM/HIGH	40	HIGH
Average for upper-middle-income	*89*	*95*	*14*	*MEDIUM*	*MEDIUM*	*56*	*HIGH*
Sousse, Tunisia	100	100	6	LOW	LOW	50	MEDIUM
Kunming, China	100	100	N.A.	MEDIUM	MEDIUM	50	HIGH
Quezon City, Philippines	99	98	39	MEDIUM	MEDIUM	20	HIGH
Bengaluru, India	70	90	25	MEDIUM	MEDIUM	40	MEDIUM
Delhi, India	75	87	33	HIGH	MEDIUM	0	LOW
Managua, Nicaragua	82	97	19	MEDIUM	LOW	10	MEDIUM
Average for lower-middle-income	*88*	*95*	*24*	*MEDIUM*	*MEDIUM*	*28*	*MEDIUM*
Lusaka, Zambia	45	41	6	MEDIUM	MEDIUM	100	MEDIUM
Nairobi, Kenya	55	50	24	MEDIUM	MEDIUM/HIGH	45	LOW
Bamako, Mali	57	0	85	MEDIUM	MEDIUM	95	LOW
Dhaka, Bangladesh	55	51	15	MEDIUM	MEDIUM	80	HIGH
Moshi, Tanzania	60	87	18	MEDIUM	LOW	35	MEDIUM
Ghorahi, Nepal	46	81	11	MEDIUM	LOW	0	MEDIUM
Average for low income	*53*	*51*	*27*	*MEDIUM*	*MEDIUM*	*59*	*MEDIUM*

For key to indicators, see Table 1.
N.A., not available

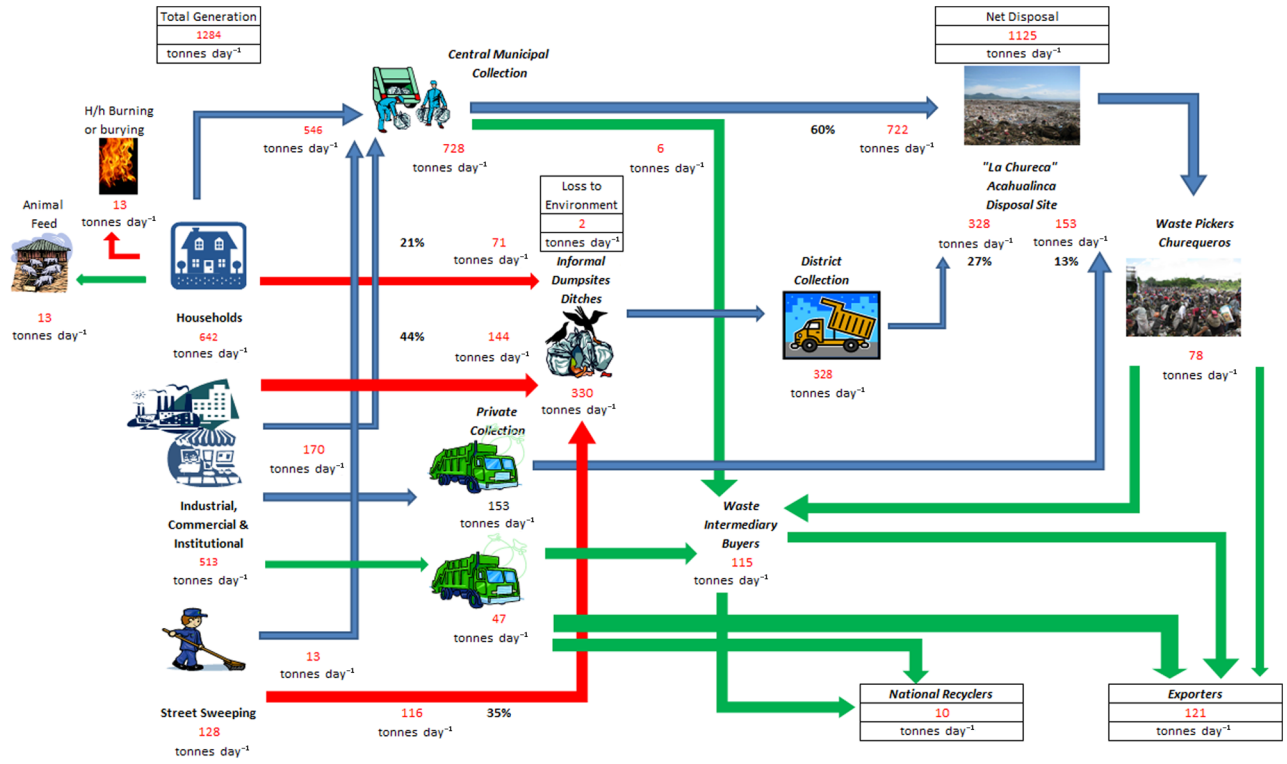

Figure 4. Process flow diagram – Managua, Nicaragua (reproduced from Olley et al., 2010 with permission).

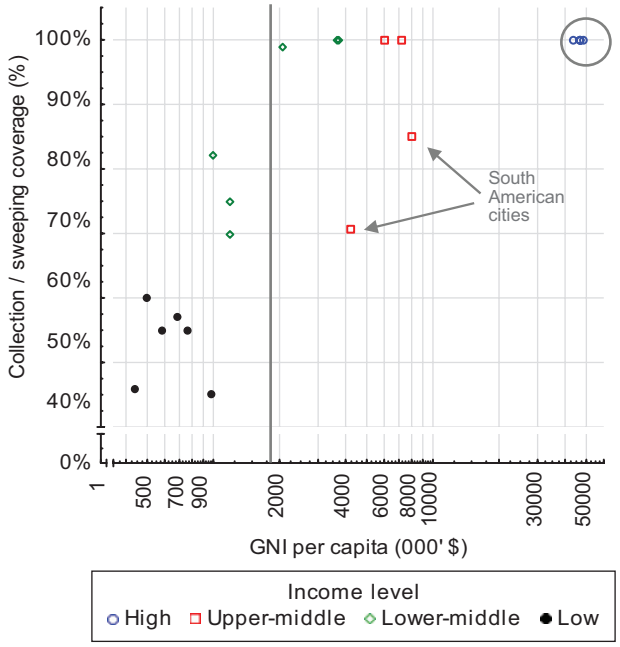

Figure 5. Scatterplot of collection/sweeping coverage against gross national income (GNI) per capita on a logarithmic scale. A clear positive correlation is evident for both HDI and for GDI capita^{-1} on a logarithmic scale (only the latter is shown here for reasons of space) ($r = 0.92$, $p < 0.0001$, $R_{adj}^2 = 0.74$). It appears that above a certain threshold (GNI capita^{-1} = US$ 1600; HDI = 0.75), most cities reach saturation level of around 100% collection coverage – the exceptions being the two South American cities. The data appear to fall into separate groups, with much lower collection coverage in the low-income cities than in all the other income categories.

2012 that it is 'common that 30-60% of all the urban solid waste in developing countries is uncollected and less than 50% of the population is served' (World Bank, undated). It was found that this is actually not so common any more, indicating that cities have been putting considerable efforts to increase service coverage. Almost half of the reference cities, including all but two of the cities with a GNI capita^{-1} above US$1600 (or an HDI of 0.75), report coverage rates of 99–100%; the exceptions being the two South American cities. This achievement is all the more remarkable when it is compared to official statistics for the EU in 1990: only seven of the then 12 member states reported collection coverage of 99–100%, with four in the range of 75–85% (ERL, 1992).

The poorest performing of the middle-income cities have collection coverage in the range of 70–90%, whereas all six of the low-income reference cities show collection coverage in the range 45–60%. This clear gap in the performance of the lower income cities means that improving collection must still be their first priority. It should be noted that some of the coverage rates reported here do conceal considerable variation between poorly served slums and well-served city centres and richer residential areas within cities, and also between urban and more rural settlements within the administrative city boundaries.

Looking beyond the data to the detailed descriptions of waste collection services in the 20 cities, what is most apparent is the huge diversity of what works and what is appropriate. Primary collection services are commonplace in low- and middle-income cities – the waste is collected directly from households and taken either to communal collection points or to small transfer stations,

Table 5. Environmental control – waste disposal

Income Level	State of the art – thermal treatment* (%)	State of the art – landfill (%)	Disposal at simple controlled sites (%)	Disposal at open dumps, losses, illegal dumping (%)
High	25	75	0	0
Upper-middle	0	75	20	5
Lower-middle	6	39	50	5
Low	0	29	23	49

*Only two reference cities, Rotterdam and Kunming, have state-of-the-art thermal treatment, so the thermal treatment/ landfill split should not to be taken as representative.

whence the waste is transported in larger vehicles to the disposal point. Primary collection is often contracted directly by the householder with individual informal or community-based, service providers for a small fee; whereas secondary collection services are generally organized by the city authorities, although they may be contracted out to the private sector. The vehicles used for primary collection are often small, including hand-, animal- or bicycle-drawn vehicles. Even for secondary collection or transfer, if the waste is largely organic and dense, then sophisticated compaction collection vehicles are both unnecessary and inappropriate, given the need for specialized maintenance and imported spare parts. The data collected on vehicle availability in the reference cities confirms the importance of local self-reliance: it is not uncommon for half or more of a city's collection fleet to be out of service at any one time, waiting for spare parts. This may be summed up as: modernization of waste collection does not necessarily mean motorization, never mind compaction (Coffey and Coad, 2010).

Environmental control – waste disposal methods and standards

Indicator 2 in Table 4 shows the percentage of total waste from the waste collection system that is destined for controlled disposal. This is a new benchmark, combining data for wastes going to either state-of-the-art, engineered landfills or thermal treatment facilities, or to simpler 'controlled' disposal sites. Table 5 provides average data by income level, but broken down into four categories of disposal site. Controlled disposal indicates a disposal site with a minimum degree of management, consisting of gate control, fencing and waste placement, which reduces the potential of water, soil and air pollution, and is widely advocated as a significant first step as a system modernizes towards sound environmental control (Rushbrook and Pugh, 1999). A simple step-by-step guide to phasing out an open dump and upgrading it to a controlled landfill is included in the UN-Habitat book (Ball and Rodic, 2010).

Indicator 2 in Table 4 shows that eight of the 20 cities are achieving 100% controlled disposal, and Table 5 shows that the average is 95% for both upper- and lower-middle-income countries. This again contradicts the World Bank website, which is still stating in January 2012 that 'In most developing countries, open dumping with open burning is the norm.' (World Bank, undated). The rapid recent progress reported here is also underlined by a comparison with the EU in 1990: uncontrolled disposal was still significant in five of the 12 member states, with levels over 50% in three (ERL, 1992).

For the low-income cities, there is still some way to go to phase out uncontrolled disposal, although the average of 51% is distorted by Bamako, which reports no controlled disposal but a very high recycling (organic valorization) rate. Many of the cities have attracted international investment to assist with developing state-of-the-art facilities – for example, Bengaluru and Delhi in India, Kunming in China and Sousse in Tunisia – whereas others have obtained donor support to upgrade their former dumpsites – for example, Belo Horizonte in Brazil, Dhaka in Bangladesh, Lusaka in Zambia and Managua in Nicaragua.

Ghorahi in Nepal is interesting as an example of a small municipality in a low-income country with very limited institutional and financial resources, which has nevertheless managed to conduct scientific studies, identify a suitable site that is accepted by the general public, and develop a well-managed state-of-the-art facility. This includes waste sorting for recycling, sanitary landfilling, leachate collection and treatment, and a buffer zone with forests, gardens and a bee farm that shields the site from the surrounding area. Key success factors included a clear vision and strong determination, which enabled them to use a small initial investment from the municipality budget to mobilize national financial support and to bring the site into operation within 5 years; and a strong landfill management committee involving local people and key stakeholders to ensure that the site is properly managed and monitored.

Rotterdam and Kunming are the only examples from the 20 cities that rely heavily on thermal treatment. The sample size is too small to draw any inferences from these data on the relative prevalence worldwide of landfill and thermal treatment as disposal routes. However, the UN-Habitat book does question how appropriate thermal treatment is to lower income countries, on the basis of both the high organic content of the waste and the need for financial sustainability (Scheinberg et al., 2010b).

Resource management

The benchmark indicator selected here is the percentage of materials recovery (valorization) through recycling and the use of organic waste in various ways in the agricultural chain. The average rate of such recycling/valorization across the 20

cities (indicator 3, Table 4) is relatively high at 30%, which is by coincidence also the figure achieved by Rotterdam, the only representative from Western Europe. Other high-income country cities in the USA and Australia have higher recycling rates (54, 61 and 72%), but so also do three low- and middle-income cities – Bamako in Mali at 85%, Quezon City in the Philippines at 39% and Delhi in India at 33%.

The city profiles include data on many attributes of resource management, which help to add both detail and further nuances to the benchmark indicator. Information is available for each city, for example, on the splits between materials recycling (glass, metals, paper, plastics, etc.) and organics recovery to the agricultural value chain; the type of organics recovery (composting, anaerobic digestion, animal feeding); on the operation within each city that recovers the most and the percentage of total valorization which that operation accounts for; and on whether the separate collection and recycling is carried out by the formal or informal sector (Scheinberg et al., 2010b). Recovery of energy as a resource is also reported – in the reference cities, such recovery was relatively uncommon.

High recycling (valorization) rates generally require the processing of both dry recyclable and organic materials, although individual cities may focus on one or the other. Quezon City relies for its high rate (39%) on dry recyclables – in this case, 24% is clean, source-separated materials, which are bought by itinerant waste buyers (IWBs). The IWBs in the Philippines are employed by local informal sector junk-shops, who in turn are organized by a local NGO, Metro Manila Linis-Ganda. In three of the cities where recovery is predominantly carried out by the informal sector (Quezon, Canete and Ghorahi), the operation recovering the most is the IWBs, while in two more (Bengaluru and Delhi), it is shown as jointly the IWBs and waste pickers who generally sort from mixed waste, operating either at the *dhalaos*, the central waste collection bins, or at the disposal sites.

Bamako is an 'outlier', with 85% valorization, no controlled disposal and a large percentage reported as illegally dumped. The largest valorization operation is the local traditional practice of *terreautage*, whereby unprocessed waste is sold to crop farmers *(céréaliculteurs)*, and waste that has already partially decomposed in the collection sites (*fumure*) is sold to the *maraîchers*, the vegetable farmers in the floodplain of the Niger River. It should be noted however that this number is a rough estimate requiring validation.

Organic wastes are used in agriculture as a compost or soil improver. The data suggest that there is still much that could be done to increase such use. A major constraint is poor product quality, which in turn is largely due to a lack of separation at source giving a contaminated feedstock to the composting process. The initiative by local professionals in WasteConcern, Dhaka, is good practice: they managed to form a joint venture with Dutch partners, obtain additional funding support via the clean development mechanism (CDM), organize collection of source-separated organic waste from households and vegetable markets, and establish a community-based composting plant. In order to ensure sustainability of the system, they assist communities in marketing the product (Sinha and Enayetullah, 2010).

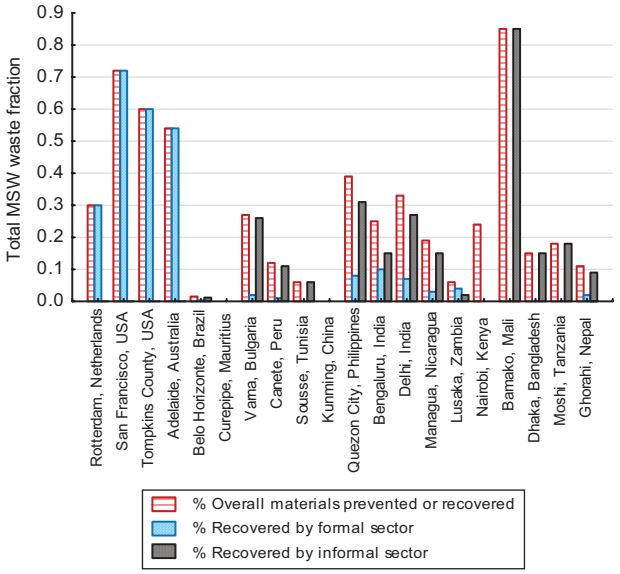

Figure 6. Materials recovery (valorization) rates, overall and by economy sectors (formal and informal) for the 20 cities. Both dry recyclables and organics are included. The cities are ranked in order of income (GNI capita^{-1}), from high (left) to low (right). Recycling in the high-income 'Western' cities is the realm of the formal sector, while the informal sector makes the largest contribution in most other cities. In certain cases (e.g. Quezon City, Delhi) the informal sector is instrumental in reaching recycling levels comparable with the western formal WM systems. Bamako is an outlier – traditionally waste materials are sold to farmers for recycling back to the land. Certain cities (Curepipe, Kunming) are not covered because of insufficient data availability/quality.

Feeding food waste to animals is the most significant valorization operation in two of the cities, Moshi in Tanzania and Sousse in Tunisia. This traditional use is also present in Nairobi, Kenya; Quezon City, Philippines; Managua, Nicaragua; and Kunming, China. Such use has often disappeared during SWM modernisation in Western countries, due to concerns about animal health; it is however still prevalent in Japan and South Korea, for example (Stuart, 2009).

The role of the informal sector. Figure 6 shows both the total material recovery rates and the split between the formal and informal sectors, for each of the cities. Material recovery in the high-income country cities is reported to be entirely carried out by the 'formal' sector, whereas in the low-income countries, the activity is predominantly in the informal sector; the middle-income cities are between these two extremes. GNI capita^{-1} can satisfactorily predict the percentage recovered by the formal sector ($r = 0.92$, $p < 10^{-7}$, $R_{adj}^2 = 0.84$).

Official statistics from 1990 show that municipal waste recycling rates in the EU ranged from 1 to 20%, with half of the 12 member states having rates between <1 – 6% (ERL, 1992). This

is corroborated by a 1989 survey of 8 European cities: the seven Western European cities had recycling rates in the range of 5–20% (Scharff and Vogel, 1994). During the past 10–20 years, high-income countries have been rediscovering the benefits and advantages of both materials recycling and organic recovery as an integral part of their waste (and resource) management systems, and have invested heavily in both physical infrastructure and communication strategies, increasing public participation in separate collection schemes, and overall recycling rates to current levels of 40% or more. Their motivation is not primarily the commodity value of the recovered materials, but rather a competitive 'sink' that the recycling market offers as an alternative to increasingly expensive landfilling and incineration.

Many low- and middle-income countries still have active informal sector and micro-enterprise recycling, reuse and repair systems which, as the data in Figure 6 show, often achieve recycling and recovery rates comparable to those in high-income countries. The key difference from formal municipal recycling in high-income countries is that the informal sector is entirely market driven – their only income is from selling the materials that they collect, separate and perhaps also add value to (e.g. through cleaning, accumulating larger quantities, densification or further processing). Similar systems previously existed in what are now the high-income cities, but were largely displaced when formal, municipal run SWM systems were introduced from the middle of the nineteenth century, driven by cholera outbreaks and public health concerns (Strasser, 2000; Velis et al., 2009; Wilson, 2007).

The informal recycling sector handle large quantities of waste which would otherwise have to be collected and disposed of by the city; this has been shown to save many middle- and low-income cities 20% or more of their waste management budget (Scheinberg et al., 2010a; 2011; Wehenpohl et al., 2007) .To give a worked example (Wilson, 2011), Mumbai's solid waste management budget was reported to be Rs 10.6 billion (US$228 million) in 2009–2010, expected to rise to Rs 15.5 billion (US$334 million) in 2010–2011 (Bhada-Tata, 2010) as the city drives to improve disposal standards. Current recycling rates by the informal sector in Delhi and Bengaluru reported in the present study are 27 and 15%, respectively. If it is assumed that an average of these figures of say 20% applies to Mumbai, then the current budget is only dealing with 80% of the city's waste generation. The saving in this budget due to existing informal sector recycling would represent avoided costs for Mumbai of more than US$50 million in 2009–2010 and more than US$80 million in 2010–2011. On the basis of this worked example, one would expect it to be a political priority of every city to work together with the informal recycling sector for the benefit of both.

There is a major opportunity here for win–win solutions – building recycling rates, protecting and developing people's livelihoods, addressing some of the negative aspects of current informal recycling on health and the environment, and reducing costs to the city of managing the residual wastes (Wilson et al., 2009). Good examples of such co-operation include New Delhi, India; Belo Horizonte, Brazil; Canete, Peru; Quezon City, Philippines and others. In New Delhi, the city has joined forces with NGOs to recognize, legitimize and facilitate the work of the informal primary collectors, who deliver their waste after recycling to the *dhalaos*, from which the city's formal private sector contractors collect the waste for transport to disposal sites. As already noted, such recognition and legitimization does bring the situation referred to as the 'informal sector' into the formal economy – so one priority is perhaps to find an alternative term to describe this important stakeholder group.

One might think that the formal sector – which includes both the public and the formal private sector – delivers all waste management services in high-income cities. However, on digging deeper into our reference cities, one encounters individuals in Rotterdam and the 'mosquito fleet' of informal vehicles in San Francisco that precedes the collection early in the morning, focusing on recyclable materials, furniture and household appliances. In Tompkins County and Adelaide there are a range of only partially formalized reuse activities, mainly in community-based organizations (CBOs), which result in what can be quite significant diversion of waste materials from disposal.

Comparing governance strategies

A novel contribution of the work reported here is its emphasis on the importance of good governance, alongside the more technological and physical components of the system.

Inclusivity

The data collected from each city in terms of inclusivity focused first on identifying the stakeholders. Far from being trivial, this research step helps to avoid one of the most common failures in attempts to introduce sustainable changes and modernize waste management systems: failing to understand how the system is already working. The data collection then focused on issues of equity between the system users in receiving a fair and adequate service and having a say in its planning and evaluation; and equity among service providers – large and small, formal and informal – in terms of a fair share of economic opportunities for providing the service or valorising materials. Indicators 4A and 4B of Table 4 present a qualitative assessment of inclusivity for both users and providers, based on a composite score from a set of qualitative indicators allowing a yes for present and a no for absent feature in the system (more details are shown in Table 1).

Inclusivity and equity of service users comprises three distinct elements, namely (a) waste collection coverage, (b) consultation and involvement of users in decision-making on policy, planning and siting of facilities, and (c) formal procedures for measuring customer satisfaction and effective feedback mechanisms between service users and service providers. While the citizens in industrialised countries as well as former socialist countries such as China and Bulgaria receive waste collection services irrespective of their social status, waste collection services in mega-cities such as Nairobi, Delhi and Dhaka do not necessarily extend to peri-urban

Table 6. Profile of informal activities in solid waste (Source: Scheinberg et al., 2010)

City	Workers, informal sector	Tonnes collected per worker per year, informal	Informal sector workers as percentage of city population (%)	Informal sector (workers km^{-2})
Bengaluru	*40,000*	*6*	*0.5*	*50*
Belo Horizonte	2300	24	0.1	7
Canete	176	7	0.4	0.3
Delhi	*170 000*	5	1.2	115
Dhaka	*120 000*	*2*	*1.7*	*329*
Ghorahi	39	8	0.1	0.5
Lusaka	480	11	0.0	1.3
Managua	3465	18	0.3	12
Quezon City	14 500*	17	0.5	90
Sousse	*150*	*27*	*0.1*	*3*
Total	352 591			

*This number pertains to households. The number of individuals is likely to be higher as it is often the case that several members of a household are involved.
Note: Figures in italics are estimated.

and slum areas. Cities such as Belo Horizonte and Quezon City are well on the way to the goal of 100% coverage, thus including slum areas. It is interesting that the reference cities with the most active citizens' platforms for involvement in waste management policy and decision-making are in lower-income countries (e.g. Moshi in Tanzania, Bamako in Mali and Ghorahi in Nepal).

Provider inclusivity does not statistically correlate with any other parameter, and user inclusivity correlates only with GNI capita^{-1}, but only a small part (34%) of its variability can be so explained ($r = 0.63$, $p = 0.003$, $R_{adj}^2 = 0.34$), indicating both a very complex nature for these parameters and the difficulty in quantifying them starting from nominal (qualitative, descriptive) data.

Just five of the 20 cities score high on user inclusivity and just four score medium/high on provider inclusivity – the highest score achieved here (Table 4). The five scoring highest on user inclusivity are the five highest income cities, whereas the four scoring highest on provider inclusivity include both Canete in Peru and Nairobi in Kenya. The two cities scoring highest on both criteria are Adelaide and Belo Horizonte. Belo Horizonte is an early adopter city in Brazil – a country which is notable for its programmes to recognize informal waste pickers as a profession and to integrate them into the waste management system and the national economy. Both of these cities have a history of high commitment to institutional development in the solid waste area. Interestingly, provider inclusivity is the only one of all the main indicators where the high-income cities do not perform best – most high-income countries do have an active community (CBO) sector, working in particular on waste prevention, reuse and recycling; the relatively low scores here reflect a need for municipalities to work more closely with either the community or informal sectors, whichever applies in their case.

It has often been quoted that up to 2% of urban populations in developing countries depend for their livelihoods on waste recycling (e.g. Medina, 2000). The authors wished to check this assertion against real data. Table 6 presents the data from the 10 cities that could provide information. In these cities, the proportion of the total city population working in the informal waste sector splits into three groups, with four cities in the range of 0.0–0.1%, another four between 0.3–0.5% and just two over 1%, namely 1.2% in Delhi and 1.7% in Dhaka. These 10 cities together have a total of 350 000 informal workers, who collect an average of just over 1 tonne capita^{-1} month^{-1}. These figures reinforce the point made earlier, on purely financial terms, about the importance of working co-operatively with the informal sector; with such a large number of the urban poor making their living from waste recycling, helping them to improve their livelihoods is a key component of working to meet the UN Millennium Development Goals.

Financial sustainability

Good waste governance requires that the system be financially sustainable. Compiling comparative – and comparable – data on costs and on cost recovery has proved to be particularly difficult: accounting systems vary widely; cost and budgeting mechanisms are often fragmented and scattered over several departments; many cities are either unable or perhaps unwilling to share information.

Despite this, data on a wide range of parameters related to financial sustainability, including costs, budgets, sources of funding, cost recovery and affordability was collected. Choosing a single benchmark indicator here was difficult: the database developed comprises six quantitative benchmark indicators, including SWM budget as a percentage of municipal budget, the percentage of population that pays for collection, reported cost recovery percentage collected via fees, SWM annual fee as percentage of annual household income and SWM budget per capita as percentage of GDP per capita. The single benchmark indicator for financial sustainability defined in Table 1 and shown in Table 4 (indicator 5) is the percentage of the population using and paying for waste collection services. This was chosen as the indicator which best serves the intention to go beyond coverage or percentage cost recovery, and which attempts to address the difference between free riding and full participation.

Table 7. Financial sustainability – affordability

Income level	City SW budget capita^{-1}	City SW budget per capita as % of GNI capita^{-1} (%)	
		Range	Average
High	US$75	0.03–0.40	0.17
Upper-middle	US$33	0.14–1.19	0.59
Lower-middle	US$10	0.40–1.22	0.69
Low*	US$1.4	0.14–0.52	0.32

*Data only available for three of the six low-income cities (for 16 out of 20 cities in total).

Table 8. Financial sustainability - fee collection for formal waste services to households

Direct charging via a waste bill or a utility bill (U)	Direct waste fee + property tax	No direct fee (financed via property tax)	No direct fee (finance from general sources)
Adelaide	Bamako	Belo Horizonte	Ghorahi
Canete	Bengaluru	Curepipe	Quezon City
Kunming		Delhi	
Lusaka		Dhaka	
Moshi		Managua	
Nairobi (U)		Sousse	
Rotterdam (U)			
San Francisco			
Tompkins County			

The benchmark indicator, as one might expect, is highest in the high-income cities, but below that income level, the data are scattered widely and over the complete range from 0–100%. Fortunately, and as already explained, the city profiles include data on many other attributes of finance and cost recovery, which help to interpret this single indicator.

Data on actual costs incurred are both scarce and unreliable, so data on budgets was used instead. The reported data show that solid waste management comprises 0–15% of the municipal budget across the nine cities where a figure could be calculated, with most in the range 3–10%, which is significantly lower than the long-quoted figure of 20–50% on the World Bank website (World Bank, undated). Table 7 summarizes SWM budget per capita, both in total and as a percentage of GNI capita^{-1}, which are also sought-after numbers: these could be calculated for 16 of the 20 cities. Budget per capita per year figures rise sharply with income levels: from just US$1.4 for the low-income cities to US$75 for high-income cities. The useable sample size for low-income countries was small (three of the six cities did not provide budget data), so it is reassuring that these figures are in line with those of Brunner and Fellner (2007) – they compared just three cities, with a budget per capita figure for the high-income city in excess of US$100 annum^{-1}, and for the two low income cities around US$1 and US$4 annum^{-1}.

When the present data are expressed as a percentage of income capita^{-1} year^{-1}, the trend is reversed: the average for the high-income-countries is only 0.17%, whereas that in the middle-income countries is 0.65%, and in low-income countries 0.32%. This highlights the challenge facing low- and middle-income countries: current expenditure levels on solid waste management are low compared to modern systems in high-income countries, yet there is relatively little room for increases before affordability problems are likely to arise in terms of citizens' ability to pay. Looking at the range of data within each income bracket as shown in Table 7, and applying the authors' long experience of working around the world, it is suggested that, as a rule of thumb, if the cost per household for the entire waste management system (however that is funded) is greater than, say, 1% of household income in low-income countries or 2% in middle-income countries, then it will likely not be affordable.

Solid waste management is in economic terms a merit good – i.e. a good, or rather a service, deemed so important, in this case for public health reasons, that the law requires that it is provided for the benefit of the entire society, regardless of the interest of the market to supply it or the users' ability (or willingness) to pay for it. This means that the role of the city needs to remain strong, if not in provision, then in regulation, of the services. It is also practically impossible to exclude non-payers, as the service is prone to 'free-rider' behaviour. For such reasons, cost recovery from paying users – although considered important – is not the central feature of financial management in most of the reference cities, as witnessed by the variability in the benchmark indicator discussed above (Rodic et al., 2010). Rotterdam is one of the exceptions where the users' fee is actually calculated based on the real costs incurred.

Table 8 categorizes the broad approach taken to fee collection - each city has its own approach to financing and cost recovery within its unique context. Half of the 20 cities use one bill, either specific to waste or collected through the utility company. Most of the others either supplement the direct bill with a contribution from property tax, or rely entirely on property tax or municipal

income tax. Approaches to affordability vary: while deliberately keeping the fee low, Belo Horizonte is dedicated to provide 100% coverage and get all users to pay; Kunming, Bengaluru and Managua also keep the fee low but do not apply punitive measures for non-payers even though the payment rate is low at 40–50%; Moshi, Tanzania, and Curepipe, Mauritius, have cross-subsidising – poor people do not pay. In Ghorahi, Nepal, and in some barangays (neighbourhoods) of Quezon City, no waste fee is currently charged to the households.

Sound institutions, proactive policies

A strong and transparent institutional framework is essential to good governance in solid waste. Without such a framework, the system will not work well over the long term. Indeed, it was suggested at the 2001 UN-Habitat World Urban Forum (Whiteman et al., 2001) that the cleanliness of a city and the effectiveness of its solid waste management system could be useful as a proxy indicator of good governance. The adequacy of services to lower-income communities also reflects on how successfully a city is addressing issues of urban poverty and equity. For waste management to work well, the city also needs to address underlying issues relating to management structures, contracting procedures, labour practices, accounting, cost recovery and corruption. Clear budgets and lines of accountability are essential.

Measuring institutional capacity is difficult. Indicator 6 in Table 4 shows a benchmark indicator for 'degree of institutional coherence': more than half the cities score 'high' against this indicator, with just three scoring 'low'. Among the parameters that contribute to this indicator (see Table 1) are two relatively unusual data points relating to the organizational chart and the budget, respectively. One data point asks how high in the organizational chart is it necessary to go to find a management position responsible for all solid waste and recycling functions. In terms of budget, the assessment is based on the number of budget lines that contribute to some aspect of solid waste management, and the percentage of all budgeted costs which fall under the largest of these budget lines: the higher this percentage, the higher the level of institutional coherence in the waste system.

In the reference cities, there are examples of strong political commitment and leadership showing tangible results, but also of weak and disinterested institutions with accompanying poor performance of the SWM system. The current SWM system in Belo Horizonte is the product of a gradual learning process in urban and environment management initiated a century ago, combined with the contemporary efforts to provide services to all citizens, including those in slum areas (*favelas*). In Quezon City, solid waste management came together as a comprehensive programme within the mayor's vision to create a 'quality community' for city residents. In Kunming, China, strong central planning and determined implementation, combined with privatization of street sweeping services and thermal treatment, have resulted in reliable, robust and modern waste services, despite inadequate cost recovery from the fees. Ghorahi, Nepal, has demonstrated that financial constraints can be overcome by committed leadership in combination with a genuine participatory approach. As a small town in the lowest GNI capita^{-1} country included in the study, Ghorahi has managed to construct and operate a modern landfill with no foreign financing.

In contrast, in Managua, inadequate collection services can be ascribed to fragmentation of various solid waste functions with little central coordination, weak governance and lack of political commitment, as well as lack of financial resources. Despite a number of studies aimed at modernizing solid waste management in Managua, carried out in the last 15 years and financed by the international donors, the city still has no disposal alternative to open dumping – although two on-going projects aim to change that. The situation in Nairobi is equally challenging regarding both inadequate waste collection beyond the central business district and open dumping. With reports of previous donor-funded studies on the shelf, city authorities have not succeeded in ensuring support from the international community to address SWM services and the underlying governance issues in the city.

Reflections and recommendations

The decision to seek new data from 20 widely differing cities, and its analysis through the ISWM lens, has yielded some interesting insights and also some surprises which challenge conventional wisdom.

The need for good quality data

Two major outcomes of the project reported here have been to test and demonstrate a new methodology for compiling baseline information on SWM in a city, which goes beyond either solid waste engineering or social aspects alone to a broader, more balanced view; and to obtain data and responses from countries as different as China and Mauritius, Tanzania and Philippines, Nicaragua and Bangladesh. The 20 reference cities reported here have provided a database which is probably unique, and which is believed to offer a better basis for the quantitative comparison of solid waste management around the world than has been available before. However, that comparison remains a challenge: definitions of what a particular item of data means varies widely, both between cities and even between stakeholders within the same city.

The availability and reliability of the data from the cities was also generally poor. Not all wastes collected are weighed; it is not clear how much waste is generated, as opposed to waste collected or delivered for disposal; and waste characterization studies are relatively rare and often out-of-date, inadequately designed so they do not capture seasonal variations and certainly not conducted regularly enough to pick up longer term trends.

We suggest that, if a city aspires to a 'modern' waste management system, then a good data collection and management system needs to be seen as a one of the key components. It is a familiar saying that 'If you don't measure it, you can't manage it'. Without proper data collection and management systems, it is

difficult to be accountable and transparent, or to make sound strategies and budget for them. If knowledge is power, then a city without knowledge of its solid waste system may lack the power to make positive changes. So, the quality of waste data in a city could be viewed as a proxy measure for the quality of its overall management system, of the degree of commitment of the city, or even of the city governance system. On this new indicator, most cities would not perform well.

We support UN-Habitat in urging donor agencies and others involved in promoting improved SWM to adopt this methodology in their future work. Already, since completion of the main project, the methodology has been used for developing new city profiles, for example, for Bahrain (Al-Sabbagh et al., 2012). As data for more cities become available, and the sample size becomes larger and more representative, it will become appropriate to undertake additional and more detailed statistical analysis.

Lessons learnt

The stories from the 20 reference cities, rich and poor and located in all parts of the world, show that it is possible to make progress in modernizing and improving the solid waste management system under all kinds of circumstances. There is no 'one size fits all': rather, there is strength in diversity. Cities deploy a wide variety of ideas to overcome obstacles, some of which are very innovative, some of which draw upon tradition; some are firmly embedded in local culture and habits, some aim at changing habits and attitudes (Rodic et al., 2010).

The ISWM lens used here focuses attention not only on the performance of the physical systems but also on the key governance factors. If the city cannot cover at least the costs of day-to-day operations, the system is not going to be sustainable, regardless of any access to grants and loans for capital investments from the central government or international financing agencies. If the municipal authorities do not have adequate knowledge and capacity to monitor the performance of a private service provider, if the collection system in place is not in accordance with citizens' needs and preferences, if the measures are imposed rather than discussed and negotiated with the system users, then, the system will not be embedded and sustained by the society and will not perform as designed.

The use of 'better' or 'more advanced' technology cannot resolve these kinds of issues. Such technologies are continually being sold in middle- and low-income countries, not least because of marketing problems in high-income countries. Using an ISWM lens, advanced or for that matter any proposed technologies would need to pass a number of very stringent tests: Is the technology suitable for the local waste composition? Would the technology compete with existing or future recycling? Is the technology affordable for the local community? Is the waste governance system well enough developed to support the proper application/operation of the technology? Based on our experience, sophisticated waste-to-energy technologies are unlikely to pass these tests in most middle- or low-income countries over a medium-term time horizon.

The question of affordability is critical. If the cost per household for the entire waste management system (however that is funded) is greater than, as a guideline, 1% of household income in low-income countries or 2% in middle-income countries, then it is likely *not* affordable.

In summary, a reliable approach is to be critical and creative; to start from the existing strengths of the city and to build upon them; and to involve all the stakeholders in designing their own local models. Learning from each other in a global community of practice provides an opportunity to 'pick and mix', adopt and adapt the solutions that work in a particular local situation. Even the high-income cities in our sample have something to learn from their lower-income colleagues.

If a city is at a relatively early stage of the journey of modernizing its solid waste management system, then it is important to understand what already works and build on it, rather than beginning from scratch. The key here is to identify simple, appropriate and affordable solutions that can be implemented progressively, giving the inhabitants the best system they can afford. Early steps are likely to include extending collection to the whole city and phasing out open dumps by replacing them with controlled disposal sites. But that is not enough: an ISWM approach is to focus on building up existing recycling rates, and on taking measures to bring waste growth under control. This is particularly important, as every tonne of waste reduced, reused or recycled (the 3Rs) is a tonne of waste that the city does not have to pay to collect and dispose safely. There are win–win solutions, where the city authorities, citizens, businesses and the informal/micro-enterprise sectors work together to protect public health and the environment, progress the 3Rs and contribute to sustainable resource management and sustainable development of the world community.

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References

Al-Sabbagh MK, Velis CA, Wilson DC and Cheeseman CR (2012) Bahrain's resource management performance: a systematic account of municipal waste and secondary material flows and organizational aspects. *Waste Management & Research* 2012: in press.

Ball J and Rodic L (2010) Phasing out open dumps, Key Sheet 8. In Scheinberg A, Wilson DC and Rodic L (eds) *Solid Waste Management in the World's Cities*. Third edition in UN-Habitat's State of Water and Sanitation in the World's Cities Series. London and Washington DC: Earthscan for UN-Habitat. pp. 111–112.

Bhada-Tata P (2010) The potential for waste-to-energy in India. *Waste Management World* September–October: 45–46.

Brunner PH and Fellner J (2007) Setting priorities for waste in developing countries. *Waste Management & Research* 25: 234–240.

Chalmin, P. and Gaillochet C. (2010) *2009 World Waste Survey. From Waste to Resource*. Paris, France: Economica Editions.

Chung S-S and Poon C-S (2001) Characterisation of municipal solid waste and its recyclable contents of Guangzhou. *Waste Management & Research* 19: 473–485.

Coffey M and Coad A (2010) *Collection of Municipal Solid Waste in Developing Countries*, 2nd edn. Nairobi, Kenya: UN-Habitat.

ERL (Environmental Resources Limited) (1992). *Quantification, Characteristics and Disposal Methods of Municipal Waste in the Community – Technical and Economic Aspects*. Report commissioned and published by the European Commission, Brussels.

Hoornweg D and Thomas L (1999) *What a Waste: Solid Waste Management in Asia*, Urban and Local Government Working Paper No 1. Washington, DC: World Bank.

IJgosse J, Anschütz J and Scheinberg A (2004) *Putting Integrated Sustainable Waste Management into Practice: using the ISWM Assessment Methodology as Applied in the UWEP Plus Programme (2001–2003*). Gouda, The Netherlands: WASTE.

Medina M (2000) Scavenger cooperatives in Asia and Latin America. *Resources, Conservation and Recycling* 31: 51–69.

Mvulirwenande S and Rodic L (2012) *Benchmarking in Dutch Municipal Solid Waste Management*. In preparation.

Olley J, IJgosse J and Rudin V (2010) *Managua City Profile*, for the UN Habitat's Third Global Report on Water and Sanitation in the World's Cities *Solid Waste Management in the World's Cities*. Unpublished report.

Rushbrook P and Pugh M (1999) *Solid Waste Landfills in Middle- and Lower-Income Countries – A Technical Guide to Planning, Design and Operation*, Technical Paper No 426. Washington, DC: World Bank

Rodic L, Scheinberg A and Wilson DC (2010) Comparing solid waste management in the world's cities. Key-note paper at ISWA World Congress 2010. *Urban Development and Sustainability – a Major Challenge for Waste Management in the 21st Century*, Hamburg, Germany, 15–18 November 2010. http://www.iswa.org/uploads/tx_iswaknowledgebase/Rodic.pdf (accessed 21 January 2012)

Scharff C and Vogel G (1994) A comparison of collection systems in European cities. *Waste Management & Research* 12: 387–404.

Scheinberg A (2011) *Value Added, Modes of Sustainable Recycling in the Modernisation of Waste Management Systems.* PhD dissertation, Wageningen University, The Netherlands. Gouda, The Netherlands: WASTE.

Scheinberg A, Simpson M, Gupt Y, et al. (2010a) *Economic Aspects of the Informal Sector in Solid Waste. Main Report, October2010*. Research report prepared by WASTE, SKAT, and city partners for GTZ - Deutsche Gesellschaft für Technische Zusammenarbeit and CWG - Collaborative Working Group on Solid Waste Management in Low- and Middle-Income Countries. Eschborn, Germany: GTZ. http://www.gtz.de/de/dokumente/gtz2010-en-economic-aspects-waste.pdf (accessed 25 August 2011).

Scheinberg A, Wilson DC and Rodic L (2010b) *Solid Waste Management in the World's Cities*. Third edition in UN-Habitat's State of Water and Sanitation in the World's Cities Series. London and Washington DC: Earthscan for UN-Habitat.

Scheinberg A, Spies S, Simpson MH and Mol APJ (2011) Assessing urban recycling in low- and middle-income countries: building on modernised mixtures. *Habitat International* 35: 188–198.

Schübeler P (1996) *Conceptual Framework for Municipal Solid Waste Management in Low-income Countries*. UMP/SDC Collaborative programme on Municipal Solid Waste Management in Developing Countries. Urban Management Programme (UMP) Working Paper Series, No. 9. St Gallen, Switzerland: SKAT.

Sinha AHMM and Enayetullah I (2010) Waste concern and worldwide recycling: financing dhaka market composting with public-private partnerships and carbon credits, Key Sheet 9. In Scheinberg A, Wilson DC and Rodic L (eds) *Solid Waste Management in the World's Cities*. Third edition in UN-Habitat's State of Water and Sanitation in the World's Cities Series. London and Washington DC: Earthscan for UN-Habitat. pp. 117–123.

Strasser S (2000) *Waste and Want: a Social History of Trash*. New York: Owl Books.

Stuart T (2009) *WASTE – Uncovering the Global Food Scandal*. London and New York: Norton.

UNDP (2009) *Human Development Report*. http://hdr.undp.org/en/humandev/ (accessed 20 October 2010)

UN-Habitat (2008) Urban environmental risks and burdens.In: *State of the World's Cities 2008/2009 – Harmonious Cities*. London and Washington DC: Earthscan for UN-Habitat, Chapter 3.1 p. 129.

Van de Klundert A and Anschütz J (2001) Integrated sustainable waste management – the concept. In: Scheinberg A (ed.) *Integrated Sustainable Waste Management: Tools for Decision-makers, Set of Five Tools for Decision-makers – Experiences from the Urban Waste Expertise Programme (1995–2001)*. Gouda, The Netherlands: WASTE. http://www.waste.nl/page/513 (accessed 25 August 2011).

Velis CA, Wilson DC and Cheeseman C (2009) Nineteenth century London dust-yards: a case study in closed-loop recycling and zero waste. *Waste Management* 29: 1282–1290.

Wehenpohl G, Scheinberg A, Simpson M, et al. (2007) Economical impact of the informal sector in solid waste management in developing countries. In: Proceedings Sardinia 2007, Eleventh International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy; 1–5 October 2007, Session C3.

Whiteman A, Smith P and Wilson DC (2001) *Waste Management: An Indicator of Urban Governance*. Paper prepared for the UK Department for International Development (DFID) and submitted by DFID to the UN-Habitat Global Conference on Urban Development, New York, June 2001, www.davidcwilson.com/Waste_Management_An_Indicator_of_Urban_Governance.pdf (accessed 25 August 2011).

Wilson DC (2007) Development drivers for waste management. *Waste Management & Research* 25: 198–207.

Wilson DC (2011) Acting alone to partnerships – Strategic approach for sustainable municipal waste management. In: UN-Commission for Sustainable Development (CSD) Intersessional Conference on Building Partnerships for Moving towards Zero Waste, 16–18 February 2011, Chinzanso, Tokyo, Japan. http://www.uncrd.or.jp/env/110216csd19.htm (accessed 08 December, 2011).

Wilson DC, Araba AO, Chinwah K, et al. (2009) Building recycling rates through the informal sector. *Waste Management* 29: 629–635.

Wilson DC, Rodic L, Scheinberg A, et al. (2010) Comparative analysis of solid waste management in cities around the world. In: Proceedings Waste 2010: Waste and Resource Management – Putting Strategy into Practice. Stratford-upon-Avon, Warwickshire, England, 28–29 September 2010. Stanton-on-the-Wold: Waste Conference Limited.

World Bank (2010) How we classify countries. http://data.worldbank.org/about/country-classifications (accessed 19 October 2010).

World Bank (Undated). Key Obstacles section, Urban Solid Waste Management page, under Urban Development, on the World Bank website. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUSWM/0,,contentMDK:20239149~menuPK:497508~pagePK:210058~piPK:210062~theSitePK:463841,00.html (accessed 21 January, 2012).