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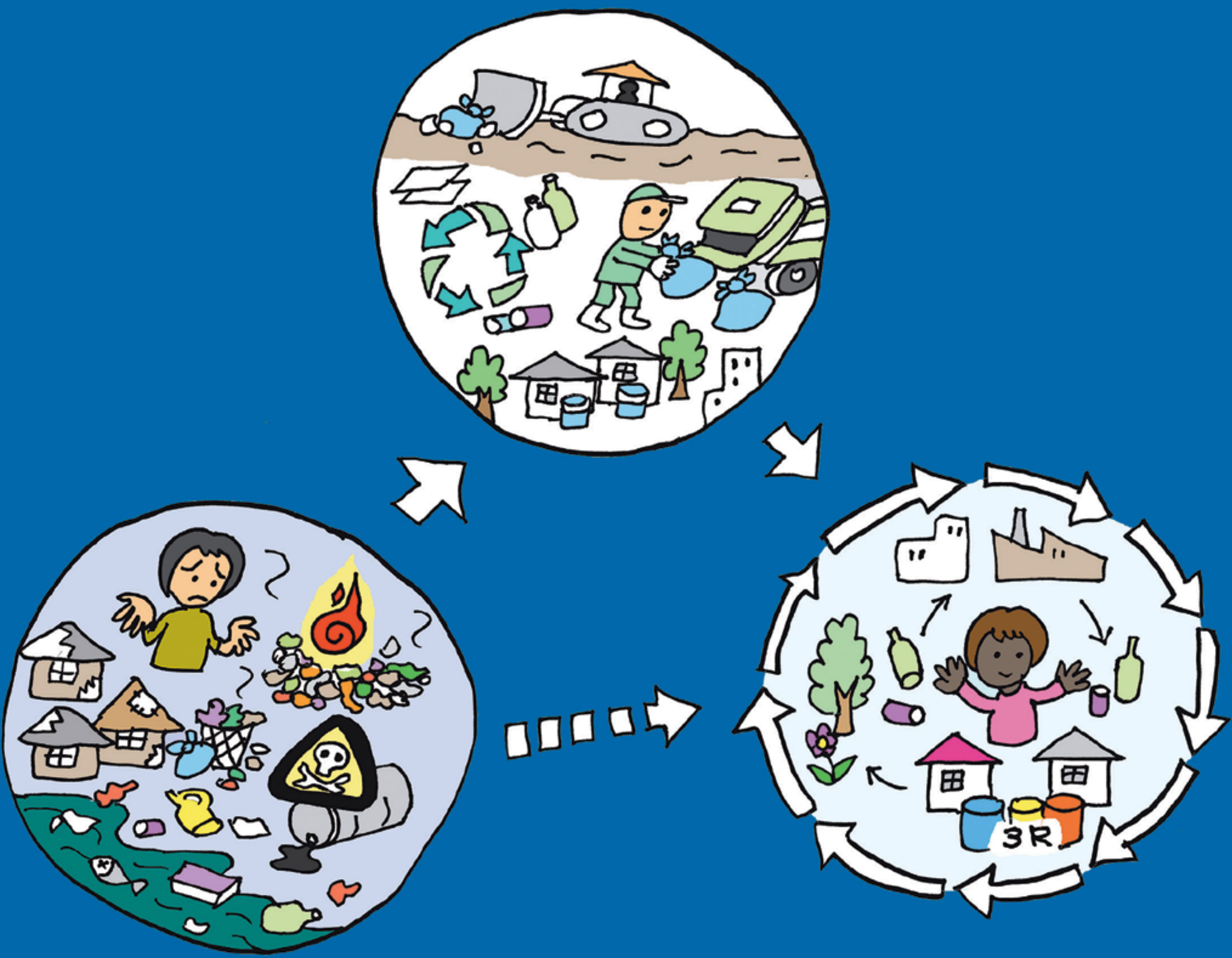
International Solid Waste Association

Global Waste Management Outlook



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CHAPTER

3

WASTE MANAGEMENT: GLOBAL STATUS

Chapter 3 provides a context or setting to the GWMO by presenting data as an evidence base regarding waste generation and its management across the world.

The Chapter starts by looking at the relative quantities of different types of wastes from various sources (Section 3.2). The focus then turns to municipal solid waste (MSW) where data on quantities and composition as well as past trends and future projections are presented (Section 3.3). Section 3.4 overviews the status of MSW management across income groups and regions. It focuses first on the protection of public health by ensuring that all wastes are collected, and then on environmental protection by phasing out uncontrolled disposal and open burning of waste.

The later sections focus on resource recovery (Section 3.5), looking at collection for recycling, the importance of source segregation, and available technologies for resource recovery. This is followed by an examination of the global industry in secondary materials (Section 3.6).

The chapter is followed by a series of Topic Sheets focusing on waste streams of particular interest, including construction and demolition waste, hazardous waste, e-waste, plastic waste and marine litter, disaster waste and food waste.

3.1 SUMMARY OF THE CHAPTER – KEY MESSAGES ON THE GLOBAL STATUS OF WASTE MANAGEMENT[1]

- A best 'order of magnitude' estimate of the total global arisings of municipal solid waste (MSW) is around 2 billion tonnes per annum. A broad grouping of 'urban' wastes, including MSW, commercial and industrial (C&I) waste, and construction and demolition waste (C&D), is estimated at around 7 to 10 billion tonnes per annum.

- Although generation rates vary widely within and between countries, MSW generation per capita is strongly correlated with national income. In high-income countries, MSW generation rates are now beginning to stabilize, or even show a slight decrease, which may indicate the beginning of waste growth 'decoupling' from economic growth. However as economies continue to grow rapidly in low- and middle-income countries, one can expect per capita waste generation to increase steadily.

- Waste generation is growing rapidly in all but the high-income regions of the world, as populations rise, migration to cities continues, and economies develop. In 2010, the traditional high-income countries accounted for around half of all waste generation. That is forecast to change quickly, with Asia overtaking these countries in terms of overall MSW generation by around 2030 and Africa potentially overtaking both later in the century.

- Organic fractions comprise a greater percentage of the MSW arisings in low-income countries (where organic waste is typically 50 to 70% of all MSW) than in high-income countries (where organics account for typically 20 to 40%). The percentage of paper appears to be proportional to income levels (23% of MSW in high-income, 19% to 11% in middle-income and 7% in low-income countries). Plastic levels generally appear high across the board (8% to 12%), not showing as much dependence on income level as other waste types. 'Dry recyclable' materials (metals, glass and textiles) range from 12% of MSW in high-income to 12% and 9% in middle-income and then 6% in low-income countries. Household hazardous waste (HHW) is estimated to make up less than 1% of all MSW across all income ranges, but its presence makes certain management options much more difficult.

- Extending MSW collection to 100% of the urban population is a public health priority. Evidence suggests that significant progress has been made in many middle-income countries over the past few years, particularly those with gross national income (GNI) per capita above USD 2500 per year. At the same time, median collection coverage is still around 50% in low-income countries and figures are much lower in some countries. It also drops sharply in the more rural areas of many countries. It is estimated that at least 2 billion people worldwide still lack access to solid waste collection.

- Eliminating uncontrolled disposal is a priority for protecting the environment. Evidence suggests considerable progress has been made. However, the 100% and 95% controlled disposal rates in high- and upper-middle income countries respectively are in stark contrast with rates that are often well below 50% in low-income countries, and 0% controlled disposal is still relatively common in rural areas in many countries. In lower-income countries, waste disposal is often in the form of uncontrolled dumpsites with open burning. It is estimated that at least 3 billion people worldwide still lack access to controlled waste disposal facilities.

- Recycling may provide a source of income, help conserve scarce resources and reduce the quantities of waste requiring disposal. However the success of recycling depends critically on materials being kept separate and clean and being found in sufficiently high concentrations. Recycling rates in high-income countries have progressively increased over the last 30 years, driven largely by legislative and economic instruments. In lower-income countries, the informal sector is often achieving recycling rates of 20 to 30% for MSW.

- The secondary materials industry operates globally, with active international 'commodity' markets for ferrous and non-ferrous metals, paper, plastics and textiles. Most secondary materials come from industry and most are utilized inside national boundaries, but a sharp increase in the availability of materials from MSW recycling since the 1990s, together with the relocation of much of the world's manufacturing industry to Asia in general and to the People's Republic of China (PRC) in particular, has led to an increasingly transboundary and even global market. The PRC accounts for 60% by weight of global imports of

1 Please refer to Annex B for details of the data sources used to compile the evidence presented in this chapter.

aluminium scrap, 70% of recovered paper and 56% of waste plastics. Other Asian countries are also major importers, with Turkey the recipient of 30% of the total world trade in steel scrap.[2]

- Resource recovery from waste includes processes both for the recovery and recycling of the organic fraction and for energy recovery. Global activity in new waste processing facilities is high. Over the past two years, waste processing investment projects worth more than 300 billion USD have been active, of which 85 billion USD was directed to MSW processing (although not all of these projects will be built). Most of this investment activity is in the high-income countries, including energy from waste projects utilizing biomass and so on.
- Some waste streams require particular focus. Topic sheets are provided in the GWMO for large-volume C&D waste; for high-risk hazardous waste and e-waste; for plastic waste and for its associated problem of marine litter, which is receiving global attention; for waste from disasters; and for food waste, the scale of which is huge when considered alongside food scarcity and global starvation.
- Mining and quarrying and agriculture and forestry residues and wastes are generally managed close to source, with most agriculture and forestry wastes either being returned to the soil as soil improvers and nutrients or used as biomass fuel. These large volume streams are thus generally outside of national waste control regimes and data are not reported. A very rough, 'order of magnitude' estimate is that each of these major sectors generates 10 to 20 billion tonnes per annum of residue and waste. Mine tailings merit further attention as waste due to their potential for health and environmental impacts.
- The definitions of waste categories vary widely; waste quantities are often not measured; national reporting systems are often weak. As a result, it is not surprising that international data on MSW generation, composition and management lacks adequate breadth and depth and is weak and unreliable. The international data situation is still worse for other waste types. Use is made here of recent work that developed indicators to benchmark the performance of a city's MSW management system on a consistent basis. It is recommended that waste and resource management data are actively included within wider international action as part of the data revolution to improve data for sustainable development, that a globally recognized and internationally agreed methodology be developed for collecting and reporting waste data at the local (municipal) and national levels, and that the available performance indicators be subjected to widespread testing, with the results used to inform further work to develop standardized indicators.

Textile waste

Compost

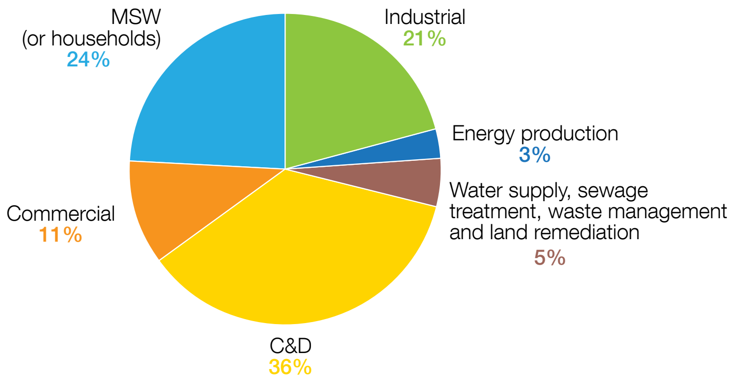
2 Excluding intra-EU trade.

3.2 OVERVIEW OF GLOBAL WASTE GENERATION

Providing a global overview of total waste generation would appear to be a fundamental element of the GWMO, but in reality it is almost impossible to do so with sufficient accuracy.[3] Where data exist, they generally refer to MSW,[4] hence that is the focus for most of this chapter. A wider compilation of data on waste from different points in the material and product life cycle exists mainly in higher-income countries, especially in OECD countries. Therefore these data have been used as a 'proxy', to show the relative quantities of waste from different sources.

Figure 3.1 suggests that the three major waste streams of construction and demolition (C&D), commercial and industrial (C&I – appearing as two segments in *Figure 3.1*) and municipal solid waste (MSW) predominate. In the higher-income OECD countries from which these data are taken, MSW is generally managed by municipalities and C&I and C&D waste by the waste generators themselves through the waste industry (through business to business [B2B] arrangements).[5] However, even in these cases there is overlap between the definitions and considerable variation between countries. The distinctions between these three major waste types are even more 'fuzzy' in developing country cities.[6]

Figure 3.1 Relative quantities of waste from different sources in the material and product life cycle



Notes: Data is for the OECD countries as a proxy, due to limitations on availability of data from the rest of the world. All data exclude agricultural and forestry and mining and quarrying wastes. Where there are significant gaps in the OECD database for a particular waste arising in a specific country, other sources have been used (using the EMC Master database [2014, n.p.] compiled for the GWMO), or an estimate has been made. Estimate of waste from a broad range of municipal, commercial and industrial sources (total waste quantity generated in the OECD countries, including construction and demolition (C&D) but excluding agricultural and forestry and mining and quarrying): **3.8 billion tonnes per annum**.

Figure 3.1 distinguishes two further types of waste, which are reported separately in the OECD database. Wastes arising from water supply, sewage treatment, waste management and land remediation represent around 5% of the total, while waste from power generation represents around 3%. These sources are interesting, as they represent the best measure available of those residues which have been removed from emissions to air and water, and concentrated as 'solid waste'.[7]

In principle, it is possible to attempt to extrapolate from the OECD data in *Figure 3.1* to estimate total worldwide waste arisings. Such extrapolation is facilitated by the availability of waste data for some non-OECD countries, in particular Russia and the PRC.[8] Extrapolating from the EMC database prepared for the GWMO to estimate 2010 worldwide MSW arisings results in an estimate of around 2 billion tonnes per annum, which is roughly twice the MSW figure for the OECD.

For the other waste streams, extrapolation is even more challenging. Based on the available information, the best 'order of magnitude' estimate of total arisings worldwide for the broad grouping of 'urban' wastes (municipal, commercial and industrial wastes, including C&D waste) comparable to the data indicated for the OECD in *Figure 3.1* is in the range of 7 to 10 billion tonnes per annum. However, more reliable, measured data are urgently needed: a major recommendation from the GWMO is to ensure that waste and resource

3 See Section 2.5.2 on the quality and availability of waste-related data.
4 See Section 3.3 for an overview of municipal standard waste generation, its composition and its properties.
5 See Chapter 5, in particular Sections 5.3 and 5.5.
6 See Section 2.2.3.
7 See Section 2.2.1.
8 See Annex B.

management data are actively included within wider international action as part of the data revolution to improve data for sustainable development.

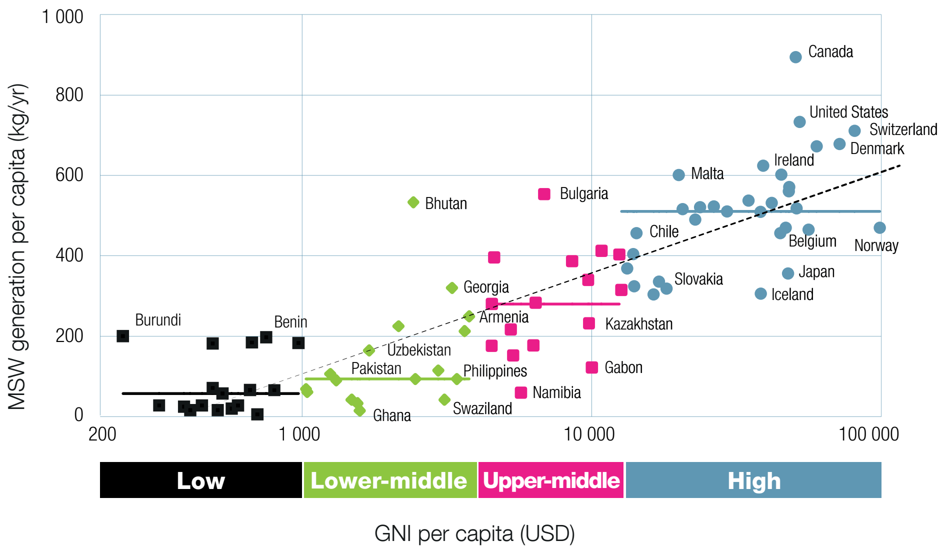
A decision was taken early in the development of the GWMO to focus on the 'higher risk' grouping of wastes included in *Figure 3.1.* The two major sectors 'Agricultural and Forestry' and 'Mining and Quarrying' had been set aside, as these sectors' residues and wastes are generally managed close to source, with most agricultural and forestry residues either being returned to the soil as nutrients or used as biomass fuel; are often outside of national waste control regimes; and data for them are generally not reported.[9] The quantities are potentially very large, as these wastes include crop residues, animal manure and wood residues from agriculture and forestry as well as rock, over-burden and processing residues from mining and quarrying. Based on data from the few countries which collect and report them, and on estimates based on production data and assumptions concerning residues per unit of production, it is possible to make rough, 'order of magnitude' estimations of total worldwide arisings of residues and wastes, which are in the range of 10 to 20 billion tonnes per annum for each of the two sectors. The main component of interest in the GWMO, due to its potential impacts on public health and the environment, is mine tailings, on which a specific follow-up study is recommended.

3.3 OVERVIEW OF MSW GENERATION

3.3.1 MSW generation

MSW generation rates vary widely within and between countries. The generation rates depend on income levels, socio-cultural patterns and climatic factors. *Figure 3.2* shows the relationship between waste per capita[10] and income levels per capita for 82 countries. Despite the 'scatterplot', there is a strong positive correlation, with the median generation rates in high-income countries being about six-fold greater than in low-income countries. There is also considerable variation within countries. For example, Brazil's national database shows state waste generation per capita in 2012 ranging from a low of 310 kg per capita per annum to a high of 590 kg per capita per annum.[11]

Figure 3.2 Waste generation versus income level by country



Notes: Based on data from 82 countries using the latest available data within the period 2005-2010. For 12 countries, the latest available data was older than 2005.

Regression: $y = 109.67\ln(x) – 651.45$, $R^2 = 0.72$

Data sources: EMC's Master Country Database (n.p., 2014) using primarily data from the EU, OECD and World Bank; Lawless (2014), Waste Atlas: Recycling and resource recovery around the world (Unpublished master's thesis). University of Leeds, Leeds, UK. Both were prepared for the GWMO (see Annex B, under Waste databases).

9 See Section 2.2.3.
10 It is important to note that data reported for many countries is likely to be MSW collected rather than generated. This not only affects interpretation of the waste generation data but also the data on waste composition.
11 Annual reports on Brazilian waste statistics (in Portuguese). See www.abrelpe.org.br

3.3.2 MSW Composition and Properties

In spite of the high variability and low reliability of source data, a comparison of average compositions relative to the countries' income level shows some interesting patterns (see *Figure 3.3).*

- One major difference is in organic fractions, which are significantly higher in middle- and low-income countries (averaging 46 to 53%) than in high-income countries (averaging 34%). Yet in fact these averages might be understating the differences. One comparative study contrasts an average of 67% across many middle- and low-income cities with 28% for cities in Europe, North America and Australia.[12] Also, the nature of the organic waste differs. In middle- and low-income countries, most organic waste is 'unavoidable', as it is the organics left over after the preparation of fresh food – organic matter that could not have been eaten. In contrast, in high-income countries there is a great deal of avoidable food waste – that is, food that could have been eaten.[13]

- The percentage of paper waste appears to be proportional to income levels, rising steadily from 6% in low-income countries, through 11% to 19% in middle-income and 24% in high-income countries. These figures are in line with data on the annual per capita consumption of paper worldwide, which ranges from 240 kg in North America, through 140 kg in Europe, to 40 kg in Asia and 4 kg in Africa. There has long been speculation that per capita consumption of printing and writing paper and newsprint in high-income countries has been falling due to electronic readers. The world average per capita consumption had shrunk by 4% in 2012 compared to the peak recorded in 2007.[14]

- While plastic levels appear generally high, they perhaps do not show as much dependence on income level as might be expected, with the averages for all income categories having a fairly narrow range of 7 to 12%. However, these averages do hide considerable variation between countries, with much higher values being reported in certain countries. For example, a regional comparative report indicated high levels for both Jordan (about 16%) and Mauritania (about 20%).[15]

- Levels of other 'dry recyclable' materials, which include metals, glass, and textiles, are all relatively low. Taken in aggregate, there is a small but steady increase in this type of waste as incomes rise, from 6% in low-income countries, through 9% and 12% in middle-income to 12% in high-income nations.

- MSW now increasingly contains relatively small amounts of hazardous substances. Often known as household hazardous waste (HHW), typical sources may include mineral oils such as motor oil; asbestos products such as roofing and heating blankets; batteries; waste electrical and electronic equipment (WEEE or e-waste); paints and varnishes; wood preservatives; cleaning agents such as disinfectants; solvents such as nail varnish; pesticides such as rat poison; cosmetics such as hair dyes; and photo lab chemicals such as developer. Statistics are unavailable on the percentage of household hazardous waste in MSW on a global basis. Estimates suggest a percentage of household hazardous waste in MSW of less than 1%, but up to 5% if e-waste is included.[16]

Waste composition affects the physical characteristics of the waste, including density, moisture content and calorific value, which in turn affect waste management and the choice of technology for collection, treatment and the 3Rs. For example, the ash content of MSW in high-income countries has decreased over the last 50 years, while the content of paper, plastics and other packaging materials has increased, significantly reducing the bulk density and increasing the calorific value. Reduced density has increased the need for compaction during collection to achieve higher and more economic vehicle payloads, while increased packaging content and rising calorific values make both recycling and energy from waste (EfW) more attractive. Conversely, the higher levels of organic waste in lower-income countries means that the waste is wetter, denser and has a lower calorific value, so there is less need for compaction during collection and the MSW may not burn without auxiliary or support fuel.

Some plastic wastes, in particular PVC, can result in air emissions of toxins such as dioxins and furans if unmanaged wastes are subjected to open burning, or if the thermal treatment and pollution control at EfW

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12 Wilson et al. (2012). Comparative Analysis of SWM in 20 cities. 13 of the 15 'Southern' middle- and low-income countries are within the range 48–81% (average 67%); while the five cities in Europe, North America and Australia (i.e. the four high-income cities plus Varna in Bulgaria) report 24–34% (average 28%). Source listed in Annex A, under Chapter 1, Waste management.

13 See Topic Sheet 11 on Food Waste and Case Study 3 on reducing food waste, both found after Chapter 3.

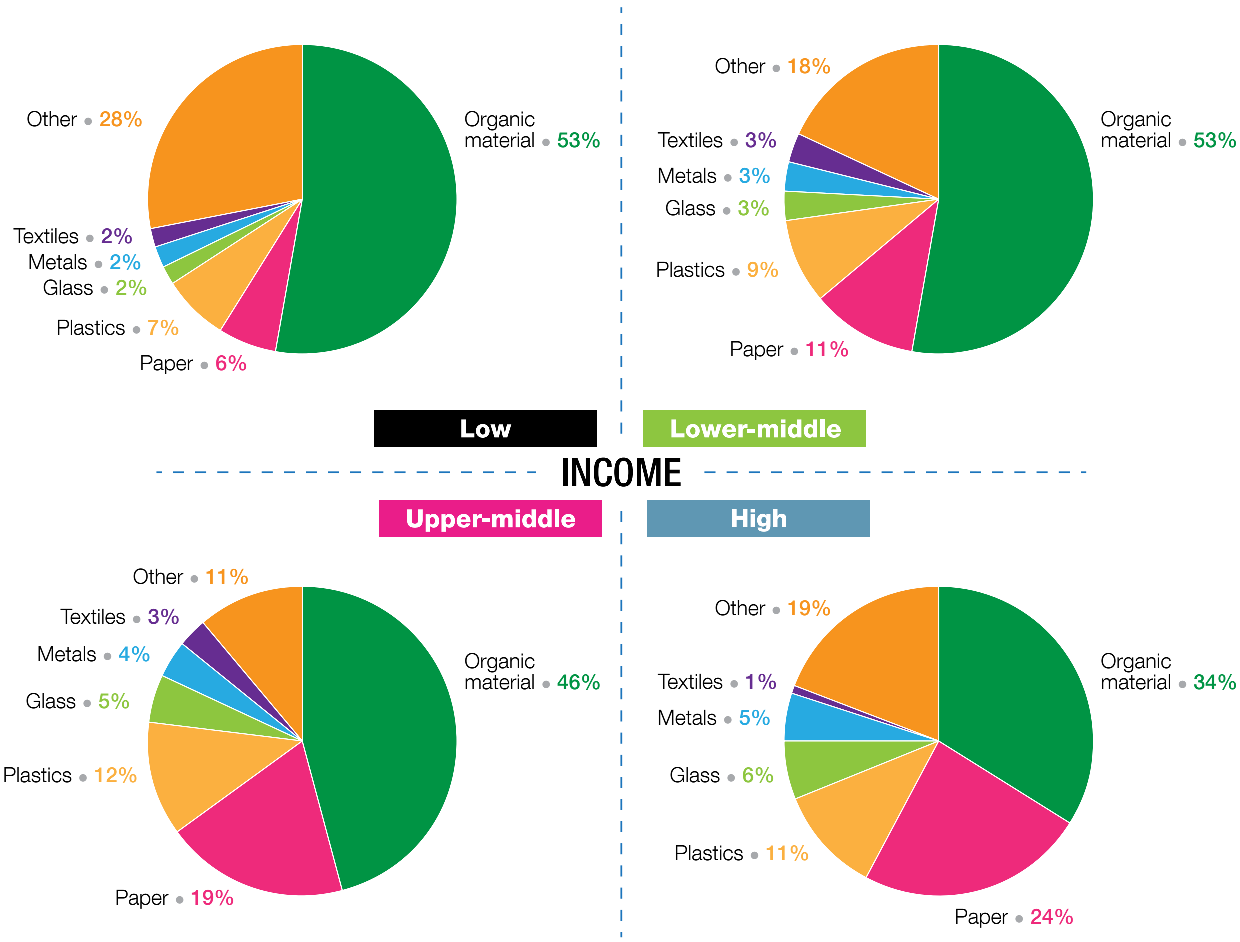
14 Bureau of International Recycling (2014). Recovered paper market in 2012 (2014 report), listed in Annex A, Chapter 3, Global secondary materials industry.

15 Sweepnet (2014a), listed in Annex A, Chapter 2, Waste data and indicators.

16 Slack et al. (2007), listed in Annex A, Chapter 3, Municipal solid waste management.

facilities are inadequate. In light of this, it is important to establish a reliable database on waste composition and characteristics and monitor the trends.

Figure 3. 3 Variation in MSW composition grouped by country income levels



Notes: Based on data from 97 countries (22 in Africa; 14 Asia-Pacific; 35 Europe; 19 Latin America/Caribbean; 2 North America; 5 West Asia). Dates of the data vary between 1990-2009. “Other” means other inorganic waste.

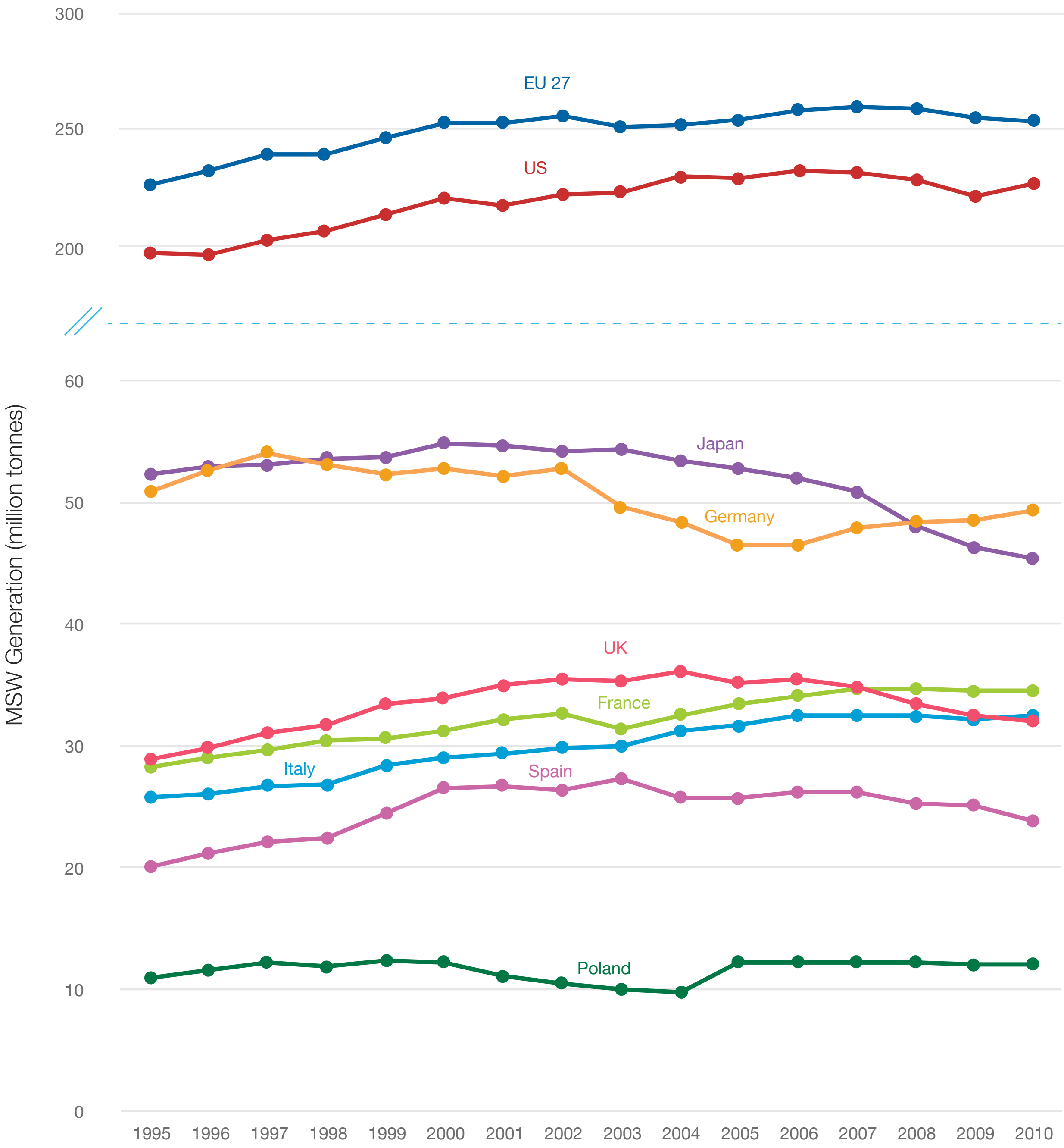
Source: EMC's Master Country Database (n.p., 2014) using primarily data from the UN and World Bank and Hoornweg & Bhada-Tata (2012)[17]

3.3.3 Trends in MSW generation

Waste generation per capita has risen markedly over the last 50 years and shows a strong correlation with income level. *Figure 3.4* shows data for the last 20 years in some high-income countries. This figure also suggests that MSW generation rates are beginning to stabilize in high-income countries, or even show a slight decrease. This is often cited as evidence for the beginning of waste growth ‘decoupling’ from economic growth, as the trend became apparent before the 2008-09 financial crisis. However, the previous rising trend may resume if economic growth returns to previous levels. Also, a contributing factor may be the shifting of manufacturing industries to emerging economies. This shift would not be such a major factor in MSW generation, but would be expected to have a larger impact on industrial waste quantities.

17 Listed in Annex A, Chapter 3, Collated data sources.

Figure 3. 4 Trends in MSW generation since 1995 in selected high-income countries



Data source: EMC's Master Country Database (n.p., 2014) using data from Eurostat and OECD

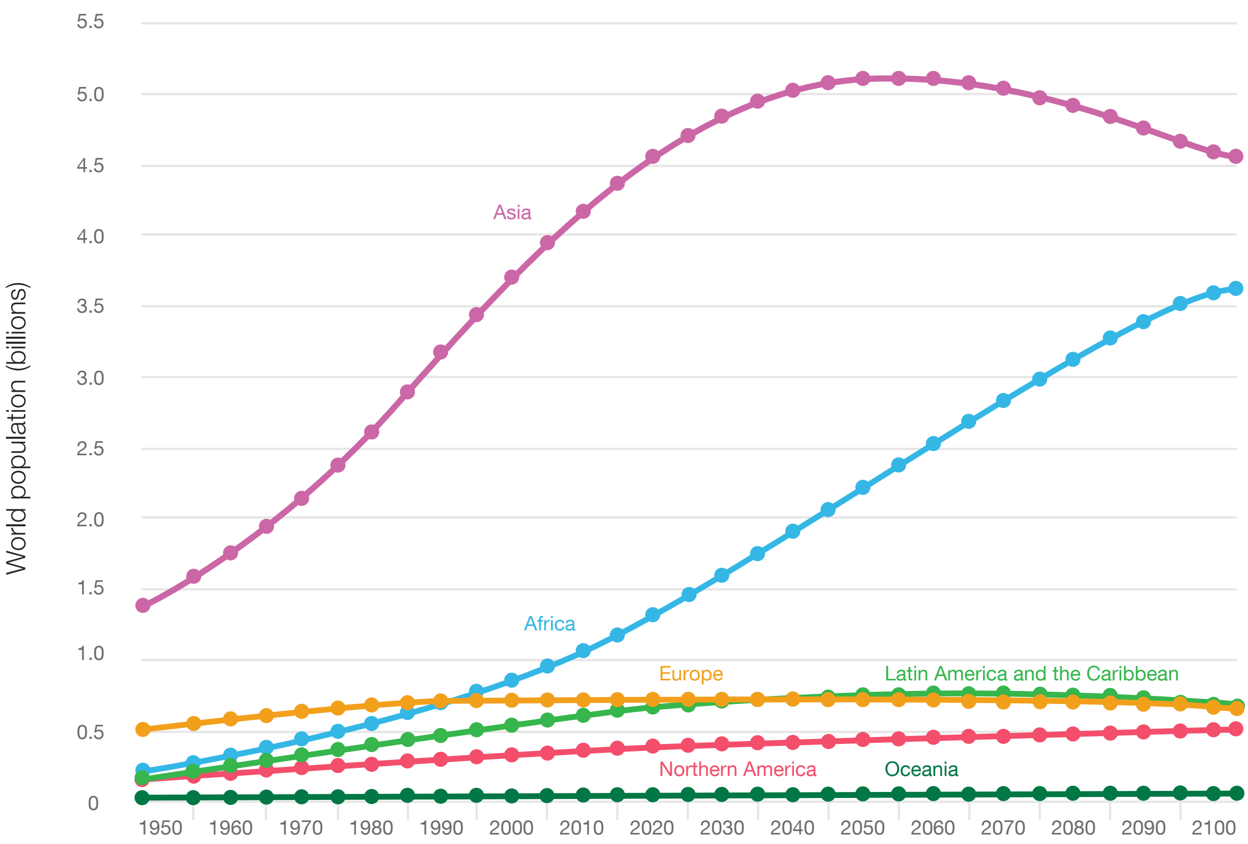
The best available data on current total world generation of MSW come from a combination of 'real' national statistics, where waste arisings have been systematically measured, recorded and reported; and calculated figures where population data have been combined with estimates for MSW generation per capita. Forward projections of both population and waste per capita data are needed to project these figures into the future and forecast future changes in MSW arisings.

Forecasting population has been a major focus for the world's statisticians. The UN's World Population Prospects[18] publishes a range of scenarios for future population growth through to 2100, although the scenarios begin to show an increasingly broad range in their forecasts beyond the next 30 years. *Figure 3.5* shows estimated and projected world population by region from 1950 to 2100 for the 'medium variant'. The general

18 UNDESA. World Population Prospects. http://esa.un.org/wpp/

trend is an initial rise, followed by a levelling out and then either a stabilization or a fall. Under this scenario, Asia is forecast to reach its peak population around 2050 while Africa continues to grow through to 2100.

Figure 3. 5 Estimated and projected world population by region



Notes: Estimates: 1950-2010; Medium variant: 2015-2100

Source: UNDESA, Population Division (2013)[19]

Since waste generation is significantly greater in urban than in rural areas, forecasting the split between urban and rural populations is also important. *Figure 3.6* presents UN data showing the percentage of people living in urban areas by country, and also the location of cities in three size ranges above 1 million people, for four 'snapshots' in time. The shift from rural to urban areas since 1970 has been marked, and the projection for 2030 reinforces the trend. The only three megacities with a population over 10 million in 1970 were in Japan and the US; by 2014, there were 28 megacities, of which 20 were in the global 'South'; by 2030, it is forecast that there will be 12 more megacities, all in the 'South'. Urban populations are already at or approaching 80% in much of the Americas, Europe, Japan and Australia; the trend of migration to the cities still has a long way to run in Asia and particularly in sub-Saharan Africa – which coincides with the regions where total population is also forecast to continue growing most strongly.

Using these data to forecast waste arisings in individual cities in the fastest growing regions provides quite startling results. To take one example, Kinshasa in the Democratic Republic of the Congo had a population of less than 4 million in 1990, had risen to 11 million by 2014 and is forecast to reach 20 million by 2030. Allowing for increases in waste per capita with development, the total MSW generation in the city now is more than three times that in 1990, and will likely have doubled again by 2030. The challenge of providing basic MSW management services to such rapidly growing cities which are already under-served is enormous.

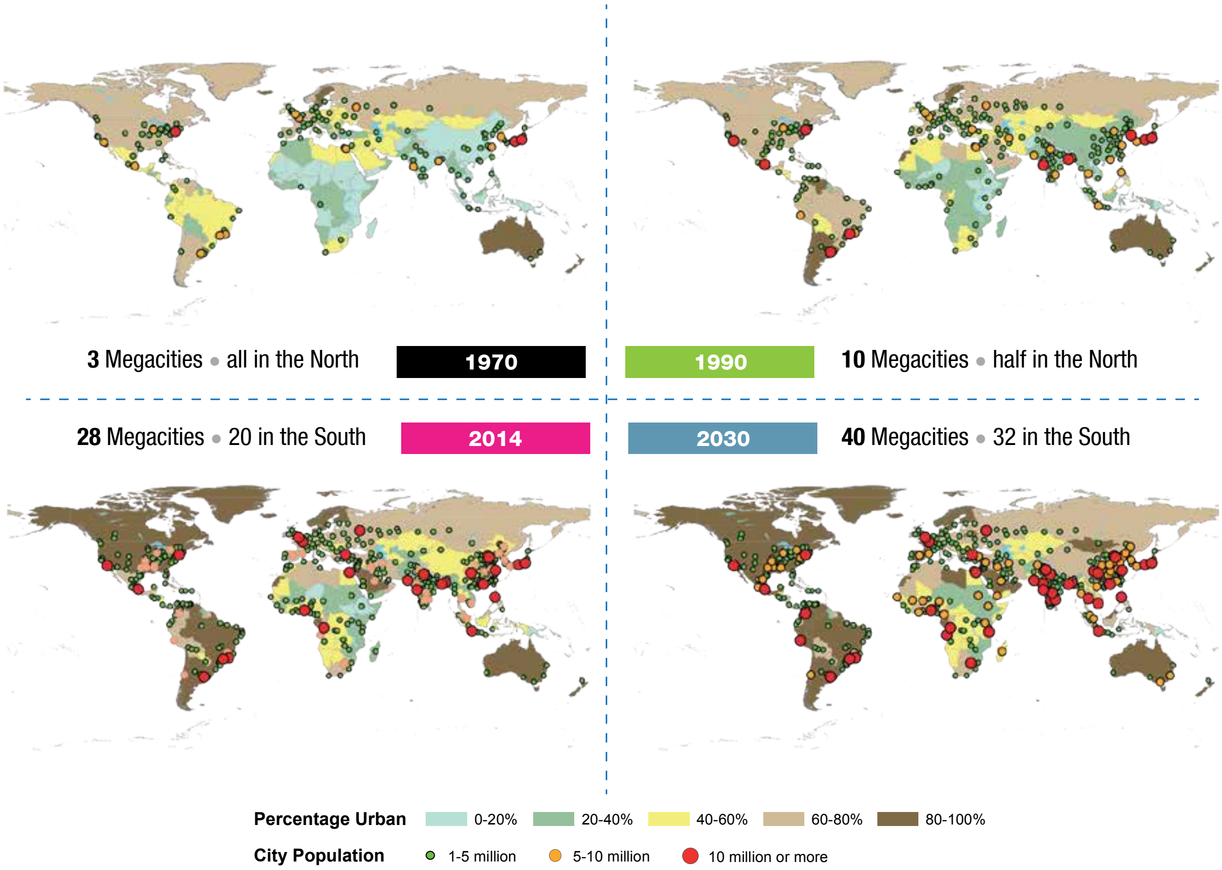
Unlike world population and urbanization trends, there are no authoritative UN forecasts of future waste generation per capita, and filling that gap is one of the GWMO's recommendations for future work. As shown in *Figure 3.2*, there is a clear link between waste per capita and income level; so unless specific waste prevention

19 UNDESA, Population Division (2013). World Population Prospects: The 2012 Revision. New York.

measures are taken, one can assume that per capita waste generation levels in the current low- and middle-income countries will increase as their economies continue to develop and gross national income (GNI) levels rise.

Box 3.1 shows the results of a recent research project which has attempted to project MSW generation forward to 2100. It is worth repeating here the caveat that any projection beyond 2050 becomes extremely speculative. It should be interpreted as a scenario of what might happen under a particular set of assumptions, rather than a forecast of what is likely to happen.

Figure 3.6 Percentage of urban population and locations of large cities, 1970 – 2030



UN disclaimer: Designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country territory or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Source: UNDESA, Population Division (2014). World Urbanization Prospects, the 2014 Revision. New York. http://esa.un.org/unpd/wup/

BOX 3.1 PROJECTION TO 2100 OF MSW GENERATION, BY WORLD REGION[20]

Figure 3.7 Total MSW generation by region

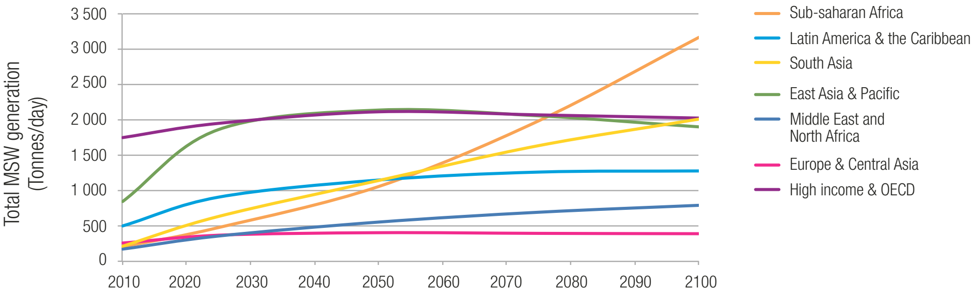
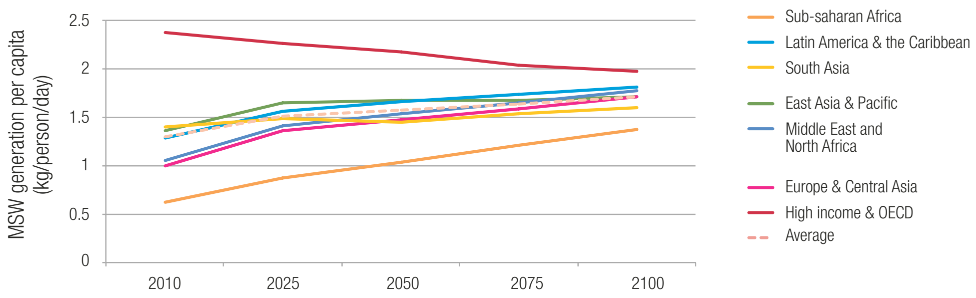


Figure 3.8 MSW generation per capita by region



Notes: In the research study from which the above graphs were taken, the authors used the five scenarios developed for the Intergovernmental Panel on Climate Change (IPCC) that relate climate change and socioeconomic factors such as population expansion, urbanization, economic and technological development.[21] The five scenarios on the shared socio-economic pathways (SSP) are: "SSP1 – Low challenges; SSP2 – Intermediate challenges, business as usual; SSP3 – High challenges; SSP4 – Adaptation challenges dominate; SSP5 – Mitigation challenges dominate." The scenario used for the projections shown in Figures 3.7 and 3.8 is SSP2, defined as "middle of the road, or business as usual," in which the current trends continue and the world makes some progress towards sustainability. In that scenario, by the year 2100, population is around 9.5 billion and slightly declining. Waste per capita is linked to GNI per capita by a series of linear relationships, the gradient of which is assumed to decline over time. Five lines are used, from 2010, 2025, 2050 and 2075.

Source: Hoornweg et al. (2015). Peak Waste: When Is It Likely to Occur? Journal of Industrial Ecology, 19 (1), 117-128. http://onlinelibrary.wiley.com/enhanced/doi/10.1111/jiec.12165/ Listed in Annex A, Chapter 3, MSW management.

While projections of outcomes so far into the future are speculative, particularly beyond 2050, they do provide some interesting insights. *Figure 3.7* shows that in the "high income and OECD" group of nations, waste generation first rises only slowly, then stabilizes and declines. As a percentage of the world total, it is declining rapidly, initially as the contribution of the two Asia regions increases rapidly, before they too stabilize. As would be expected from the previous discussion on population and urbanization, the contribution of Africa, and particularly sub-Saharan Africa, starts as relatively small, and begins to rise very quickly after 2050. What is both surprising and speculative is the forecast that Africa may become the dominant region in terms of total waste generation. *Figure 3.8* provides the corresponding data for waste per capita. It should be noted that this is part input data on how waste per capita is assumed to change as GNI per capita levels rise in individual countries, and part output, back-calculated from the results in *Figure 3.7* and population projections.

20 This box summarizes and provides commentary on a research project led by Daniel Hoornweg of the University of Ontario Institute of Technology. See Hoornweg et al. (2013, 2015), listed in Annex A, Chapter 3, Municipal solid waste management.

21 Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T. R. Carter, et al. (2010). The next generation of scenarios for climate change research and assessment. *Nature* 463 (7282): 747–756.

3.4 CURRENT STATUS OF MSW MANAGEMENT: PROTECTION OF PUBLIC HEALTH AND THE ENVIRONMENT

MSW management is an essential utility service. The first steps in ensuring sound MSW management are providing a reliable collection service to all citizens and eliminating uncontrolled dumping and open burning. The world's progress towards this target is the focus of this section.

3.4.1 Collection coverage

Providing a regular and reliable waste collection service to 100% of the urban population has been a public health objective since at least the mid-19th century. Data compiled for the GWMO from 125 countries gives the average collection coverage in low-income countries as 36% (the World Bank provides an average of 43%), lower-middle income countries 64% (World Bank 68%) and upper-middle income countries 82% (World Bank 85%), with higher income countries showing collection coverage approaching 100%. On a regional basis, collection coverage has the following ranges: Africa (25% to 70%); Asia (50% to 90%); Latin America and Caribbean (80% to 100%), Europe (80% to 100%) and North America (100%). Although these estimates are quoted as country-wide data, some incorporate the entirety of the population, both urban and rural, while others focus on urban areas. Many countries show great variation in degree of coverage among local areas or regions. For example, the national database for Brazil gives a national average of 90.2% in 2011, but the State averages range from 60% to 99.2%.[22] Similarly, in India, ministry data for 105 major cities shows collection coverage ranging from 40 to 100%.[23] Because rural areas typically have lower rates of collection coverage than urban areas, national averages on collection coverage are likely to be lower than the averages of urban areas alone.

A resident handing over waste, India

In order to assess the status of collection coverage just at the city level, *Figure 3.9* shows data on 39 cities for which Wasteaware ISWM indicators are available.[24] *Figure 3.9* appears to fall into two parts: at lower income levels, collection coverage appears to increase with increasing income, while above a certain threshold, collection reaches 'saturation' as levels approach 100%. If one apparent outlier (Canete, Peru) is set aside, then the threshold income level for this transition appears to lie at a GNI per capita in the range 2,000 to 3,000 USD per year. It needs to be borne in mind that data for entire cities may conceal a gap between the 'haves' and 'have-nots', in which often, the central business district and affluent neighbourhoods have near 100% coverage, while low-income and unlawful settlements often have none.

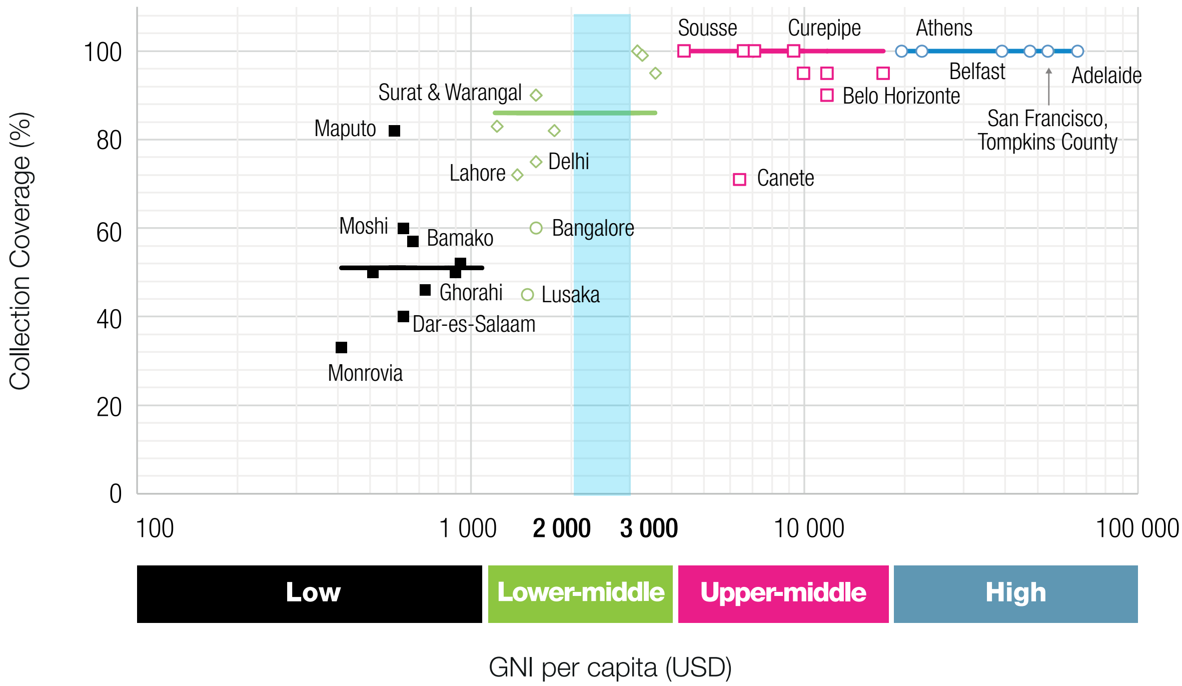
Supporting evidence comes from the 2014 comparative report for member countries of the SWEEP-Net consortium in North Africa and the Near East.[25] The consortium reports collection coverage for nine countries at an average of 63%, with an average across urban areas of 75% (range 30 to 100%), and for rural areas of 40% (four at 0%, and the others at 35%, 70%, 70%, 90% and 100%).

The World Bank assessment of collection coverage quoted on their website, that "30 to 60% of all the urban solid waste in developing countries is uncollected and less than 50% of the population is served,"[26] appears to be more of a reasonable historical baseline applying up to 2000 than a current estimate. If that is indeed the case, then the data presented here, both from the GWMO and from the World Bank's own project data,[27] suggests that there has been significant progress since that time, particularly in cities in those countries with an income above about 2,500 USD per capita per year (which represents approximately the mid-point in the

22 Annual reports on Brazilian waste statistics (in Portuguese). www.abrelpe.org.br
23 India, Ministry of Urban Development (2012), listed in Annex A, Chapter 3, Collated data sources.
24 Wilson et al. (2015), listed in Annex A, Chapter 2, Waste data and indicators. See also Section 2.5.3 for more information on indicators.
25 SWEEP-Net (2014), listed in Annex A, Chapter 2, Waste data and Indicators.
26 World Bank (n.d.). Urban Solid Waste Management. http://go.worldbank.org/A5TFX56L50
27 Hoornweg & Bhada-Tata, *What a Waste* (2012)

range of lower-middle income countries). However, it is clear that many low-income cities still have collection coverage in the range of 30 to 60%, and that the figures may be much lower in some countries, and also in the more rural areas of many countries. If the figures here for collection coverage are combined with the 2014 data for world population by country income groups,[28] then **it can be estimated that at least 2 billion people worldwide still lack access to solid waste collection**.

Figure 3.9 Collection coverage for selected cities by income level



Notes: Figure shows collection coverage versus gross national income (GNI) per capita on a logarithmic scale. The cities are those for which Wasteaware indicators[29] were available in May 2014. The blue vertical bar represents an apparent 'collection coverage threshold' (GNI of 2000-3000 USD per capita), as it was first discussed in Wilson et al. (2012). Below that threshold, collection coverage increases with income level; above the threshold, collection coverage reaches 'saturation' as levels approach 100%. The four coloured horizontal lines show the median collection coverage for each income group.

Source of data: Wasteaware – University of Leeds.

Waste collection services come in a wide variety of shapes and forms (*Box 3.2*). Services may be delivered by the formal sector, through either public- or private-sector operators, or by the community or 'informal' sector, through for example community based organizations (CBOs), non-governmental organizations (NGOs) or micro- and small enterprises (MSEs).[30] Services may be on a relatively small scale, providing primary collection to local neighbourhoods, or on a larger scale, providing either secondary collection or an integrated collection service across the city. Pickup is carried out by a range of vehicle types, such as bicycles, tricycles, tractor and trailer, tipper trucks or purpose-build compaction vehicles, and sometimes by pushcarts or animal powered carts.[31] To optimize collection systems, the use of GPS and GIS, or even route optimization software, may be relevant for large municipalities or substantial collection coverage areas.

28 World Urbanization Prospects, 2014 Edition. http://esa.un.org/unpd/wup/
29 See Section 2.5.3 as well as Wilson et al. (2015).
30 See Section 5.6 on a financing model for delivering services.
31 Coffey & Coad (2010), listed in Annex A, Chapter 3, Municipal solid waste management

BOX 3.2 EXAMPLES OF DIVERSITY IN MSW COLLECTION PRACTICES

Scale of operation

SMALLER-SCALE PRIMARY COLLECTION	LARGER-SCALE SECONDARY COLLECTION

Cycle cart, India

Close truck collection, Nigeria

Push cart, Vietnam

Open collection, Mali

Small truck collection, China

Truck collection, Spain

Primary collectors delivering waste to a secondary refuse collection vehicle, India

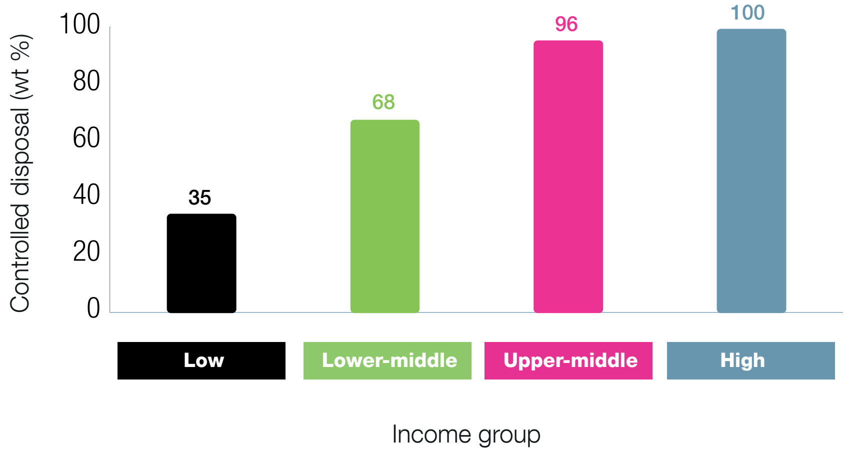
3.4.2 Controlled disposal

Uncontrolled disposal (through open dumping and open burning) was the norm everywhere until the 1960s,[32] and according to the World Bank is still the norm in most developing countries.[33] This practice gives rise to substantial public health and environmental risks. These risks are significantly increased in cases in which hazardous waste is delivered to a dumpsite alongside MSW.[34]

The high-income countries have learned that 'cleaning up the sins of the past' can be significantly more expensive than disposing of waste in an environmentally sound manner (ESM).[35] Legislation phasing out uncontrolled disposal was first introduced in high-income countries in the 1970s, and the standards required for ESM facilities have since been gradually raised.[36]

Figure 3.10 shows progress around the world in achieving the first step of eliminating open dumps and achieving controlled disposal, as measured by the Wasteaware controlled disposal indicator.[37] This novel indicator is the percentage by weight of the residual waste remaining after collection for recycling that is received at a controlled treatment or disposal facility. 'Controlled' disposal involves adequate treatment of waste and operation of secured facilities so as to meet defined compliance requirements. However, a controlled facility does not necessarily have to meet the latest EU or US standards. It can also for example be an 'intermediate' engineered landfill or an upgraded dumpsite.[38]

Figure 3.10 Controlled disposal for selected cities by income level



Notes: Graph shows average percentage of controlled disposal for each of the four standard World Bank income level categories. 'Controlled disposal' is the primary quantitative environmental indicator defined in the Wasteaware ISWM indicator set. Data are for the 39 cities for which the indicators were available in May 2014.

Source of data: Wasteaware – University of Leeds

Phasing out uncontrolled disposal practices is one of the first objectives in improving MSW management in developing countries. Besides the 100% controlled disposal generally achieved in high-income countries, the rates in upper-middle income cities (with an average of 95%) and in lower-middle-income cities (with an average of 70%) are still substantially better than the historical '0% norm'. Even the average 35% in the lower-income cities is better than the historical norm. Evidence to support this apparent recent progress is given by other sources. The Brazilian national database divides disposal into three categories: sanitary landfill, which makes up 57% of the nation's disposal on average; other landfill, at 24%; and uncontrolled dumping, at 18%. This means that in Brazil, despite relatively high controlled disposal rates, the waste from around 35 million people is dumped in an uncontrolled manner, amounting to some 15 million tonnes annually. It also suggests a comparable controlled disposal indicator likely around 80% on average. The averages for controlled disposal at

32 See Section 2.3 on drivers for waste and resource management.
33 World Bank (n.d.). Urban Solid Waste Management. http://go.worldbank.org/A5TFX56L50
34 See Box 1.2 in Chapter 1. Also, Topic Sheet 2, found after Chapter 1, provides information on 'the 50 biggest dumpsites in the world'.
35 The costs of inaction are documented in Section 5.2.3.
36 See Sections 2.3 on waste history and Section 4.3.4 on environmental legislation.
37 See Section 2.5.3 on waste management indicators.
38 Rushbrook & Pugh (1999) and Hoornweg & Bhada-Tata (2012), listed in Annex A, Chapter 3, Collated data sources.

an individual state level range generally from 40% to 90%, with one outlier below 20%. The 2014 comparative report for the SWEEP-Net consortium in North Africa and the Near East gives controlled disposal rates in the range of 10 to 70% across nine countries, with an average of 24%. As of 2010 there were 7,518 waste disposal sites officially reported in Russia, of which around 23% were MSW landfills, 7% industrial waste disposal sites, and 70% unauthorized dumps.[39] In 2011, the PRC achieved a national average controlled disposal rate of around 90%.[40]

A case study of the successful elimination of open dumping in a small town in Colombia is shown in *Box 3.3*.

In summary, the status as assessed in 2015 using the latest available data appears to be significantly better than mere dumping as the norm across developing countries. The Wasteaware data suggest that significant progress is being made by some cities in middle-income countries, with controlled disposal rates often in the range of 70 to 95%, although there is a lot of variation both within and between countries. Such achievements are impressive and compare well with the early take-up of controlled disposal in Europe in the 1970s and 1980s. The situation is much worse in low-income countries, where controlled disposal rates are often well below 50% overall and 0% in rural areas. If the figures here for controlled disposal are combined with the 2014 data for world population by country income groupings,[41] then **it can be estimated that at least 3 billion people worldwide still lack access to controlled waste disposal facilities**.

BOX 3.3 VERSALLES, COLOMBIA: AN EXAMPLE OF INTEGRATED MUNICIPAL SOLID WASTE MANAGEMENT[42]

In Versalles, a small town in Colombia, open dumping was a common sight until 1997. Through technical support from Suna Hisca, a non-profit Colombian organization, and financial support from Corporación Autonoma Regional del Valle (CVC), an integrated municipal solid waste management plan was devised. The implementation of this plan enabled Versalles to stop the contamination of its water resources and avoid potential health impacts from this practice.

The objectives of the Plan of Integrated Management of Solid Waste (PIMSW) were: (a) to achieve adequate collection, transport and disposal of municipal solid waste; (b) to engage the active participation of the stakeholders (users, the utility, the municipal administration, recyclers); (c) to get the community to practice source separation into three fractions: organics (food waste), recyclables (plastic, cardboard, metal, etc.) and sanitary waste (items contaminated with blood, urine or excreta such as sanitary towels, wound dressings, nappies, or incontinence pads); (d) to build an Integrated Solid Waste Plant to process the solid waste; (e) to create a public utility; (f) to generate employment; and (g) to improve municipal environmental sanitation. A public utility called Cooperativa Campo Verde was responsible for implementing the plan and is responsible for the collection and transportation of the waste, as well as for the operation of the plant.

As a result of the plan's successful implementation, the rate of separation at source in 2015 was above 80%, with recoverable materials marketed and organic matter transformed into compost for sale. Of the 42 tonnes of waste generated by the community per month, 27 tonnes of organic matter and 7 tonnes of recycled materials are recovered and transformed. Overall, the town has reduced by 83% the amount of waste it would have otherwise sent to landfill. *Figures 1 and 2* show the town's new weighbridge and a new vehicle for the separate collection of solid waste.

39 IFC (2014), listed in Annex A, Chapter 3 Collated data resources
40 China Statistical Yearbook 2014, listed in Annex B.
41 World Urbanization Prospects, 2014 Edition. http://esa.un.org/unpd/wup/
42 Information and text provided by Leonardo E. Navarro J. of Suna Hisca, consultant to the Housing Ministry of Colombia

3.3 RESOURCE RECOVERY

Sitting alongside the public health driver for waste collection and the environmental driver to phase out uncontrolled disposal is the resource value driver for the '4Rs' – reduce, reuse,[43] recycle and recover. The focus here is on recycling and recovery, of MSW in particular but not exclusively.

3.5.1 Collection for recycling

Most 'recycling rates' for MSW refer to the waste collected for recycling.[44] Corrections are sometimes made for subsequent 'rejects' – materials not passed on up the materials value chain for eventual recycling – but it is difficult to audit how far corrections have been done, especially in globalized value chains of secondary materials, such as in the case of waste plastics.[45] The data presented here include the collection of materials for both 'dry recycling' (e.g. paper, plastics, metals, glass, textiles) and organic recycling. The downstream processing of the collected waste materials for recycling is dealt with in subsequent sections.

© Mona Iyer

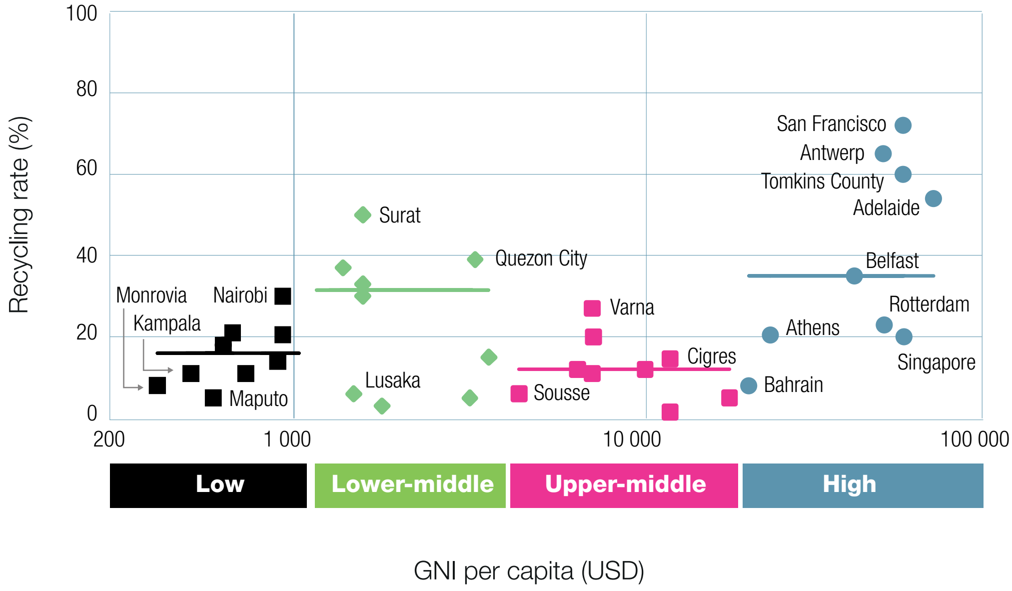
Local innovation to implement the container deposit system. The basket for 500 cans avoids manual counting at the time of deposit and refund, Kiribati

Official data for MSW recycling often come from municipal governments, which in many developing countries focus on managing the MSW they collect (or which is collected on their behalf by the 'formal sector', leaving collection of materials for recycling often to the 'informal sector'). Official data, either at the city level or compiled from city data by national governments, are thus likely to be under-reporting recycling rates. This was indeed one of the motivations behind the methodology developed to collect the data for the city-level Wasteaware ISWM indicators, that the system being studied should be the complete waste and recycling system for the city.[46] Recycling rates were calculated with the assistance of a material flow analysis (MFA) developed for each city. Waste flows were estimated and cross-checked against each other using the MFA.[47]

Figure 3.11 shows the Wasteaware recycling rates from a sample of 39 cities across various income groups. This figure shows no clear relationship between recycling rates and income levels. While recycling rates are indeed highest in the high-income countries, some low- and lower-middle income countries do collect quite reasonable percentages of their total MSW for recycling (20 to 40%). Interestingly, there is some evidence that recycling rates are lower in some of the more developed, upper-middle income countries, perhaps reflecting the history in the developed world where formalization of solid waste management as a municipal service displaced pre-existing informal recycling systems as standards of living rose, prior to the more recent 'rediscovery' of recycling and a resurgence in recycling rates in the high-income countries.[48] More research would be required to confirm this hypothesis.

43 Both 'reduce' and 'reuse' are addressed in the Topic Sheet 4 on waste prevention, which follows Chapter 2.
44 Velis & Brunner (2013), listed in Annex A, Chapter 3, Recycling.
45 Velis (2014), listed in Annex A, Chapter 3, Global secondary materials industry.
46 See Section 2.5.3 and Table 2.3, both on indicators.
47 See Section 2.4.2 on life cycle analysis.
48 See Section 2.3.1 on historical drivers in developed countries.

Figure 3.11 Average recycling rates for 39 cities by income level

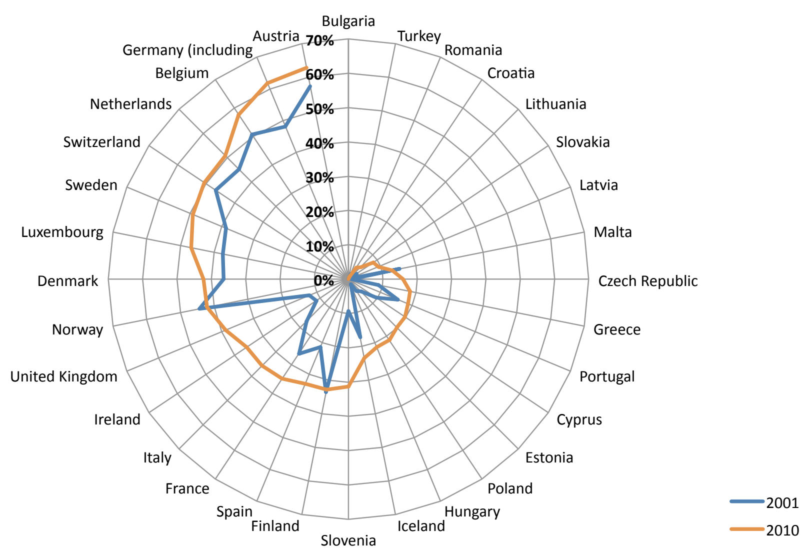


Notes: Verified and consistent data from application of the Wasteaware indicators[49] to benchmark recycling performance. In calculating recycling rates, consideration has been given to both the formal municipal SWM system and any informal/community recycling being carried out in parallel (whereas 'official' statistics often understate recycling by ignoring the latter). The cities are those for which Wasteaware indicators were available in May 2014. Data covers both dry recyclables and organics. Where possible, correction has been made for materials collected for recycling, but ultimately disposed of after initial processing (reject fraction).

Source of data: Wasteaware – University of Leeds.

Information on recycling rates in the EU countries is now collected regularly and systematically but inconsistencies in the definition still exist (e.g. regarding counting collection for recycling vs. counting outputs of MRFs and composting plants, regarding whether or not to count metals and aggregates obtained as the output of EfW combustion plants) and the level of data reliability still differs among the EU countries. *Figure 3.12* provides statistics on recycling rates in the EU countries. It may be observed that the recycling rates in the EU have increased substantially between 2001 and 2010, as the lower-performing countries have worked towards meeting the EU-wide targets.[50]

Figure 3.12 Municipal solid waste recycling in the European Union



Source: http://www.eea.europa.eu/data-and-maps/figures/municipal-waste-recycling-rates-in

49 See Section 2.5.3 as well as Wilson et al. (2015)
50 Legislation and policies to promote recycling are discussed in Sections 4.3.5 and 4.4.

3.5.2 The importance of segregation

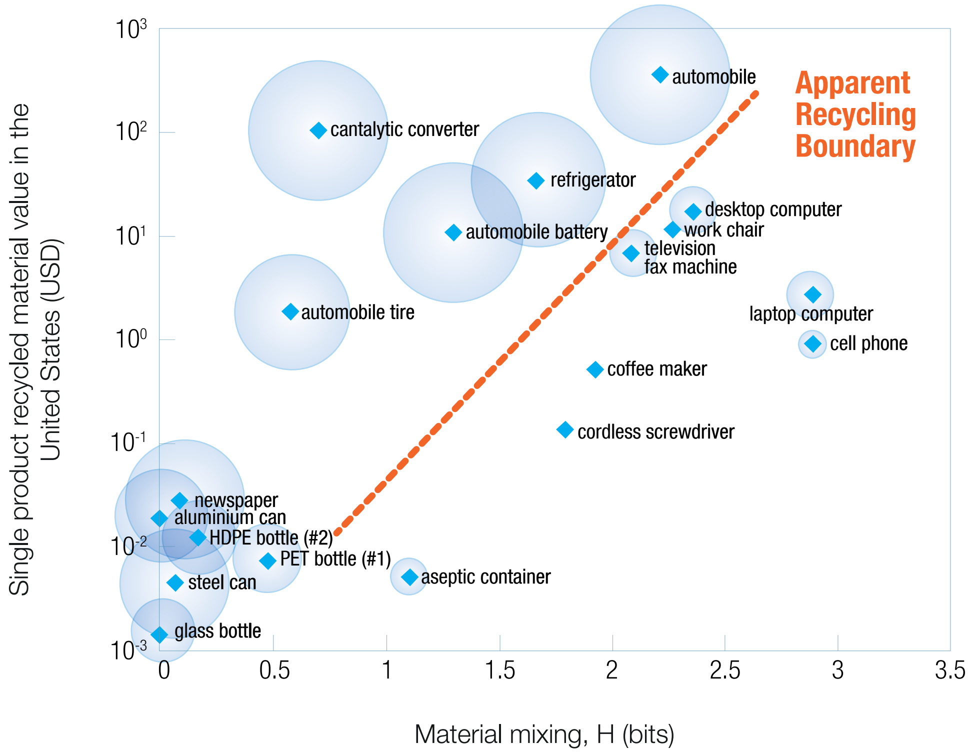
Recycling depends critically on two aspects of 'segregation'. The first is the degree of mixing of different elements or materials within a product, or the concentration at which the element is present, which can be addressed through design for recyclability. The second is to keep different 'wastes' separate at the point of generation, to ensure that they remain clean and uncontaminated by other waste streams. This can be addressed through segregation at source. These two aspects are elaborated here in turn.

Design for recyclability

Figure 3.13 shows a plot of recyclability versus the degree of material mixing for a wide range of consumer products. This clearly shows that products with lower degrees of material mixing are easier and more economical to recycle than others, with the degree of mixing at which recycling is feasible increasing as the value of the recycled materials rises. Products with a lower degree of mixing and higher values of the component materials are economic to recycle, while those with higher degrees of mixing and lower values are not.

One way to 'manipulate' this relationship is to address recyclability explicitly in the design process. For example, automobile manufacturers have recently focused on designing their products to facilitate both future dismantling (design for dismantling – DfD) and recycling (design for recycling – DfR).

Figure 3.13 Single product recycled material values

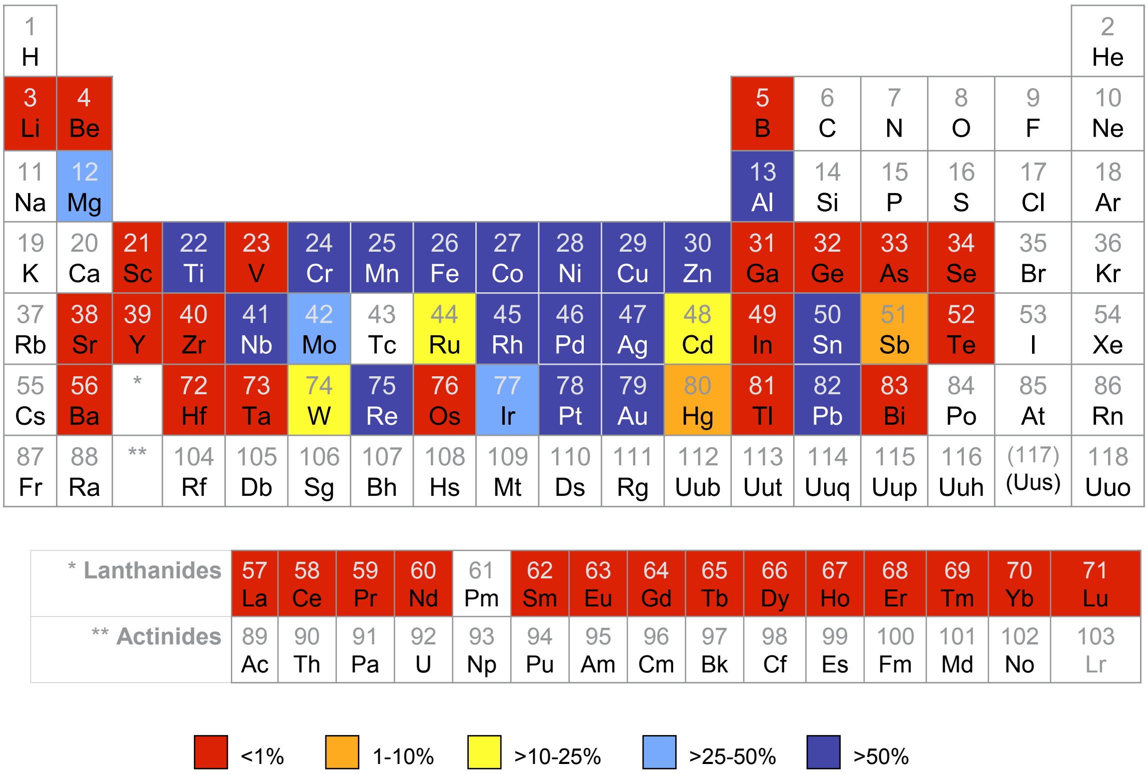


Note: Material mixing (H) and recycling rates (for 20 products in the USA. Recycling rates are indicated by the size of the spheres: for example, automobile and catalytic convertor recycling rates are 95%, newspapers 70%, PET bottles 23% and televisions 11%. The 'apparent recycling boundary' separates the graph into two regions: where recycling tends to take place and where it tends not to take place. Material mixing incorporates the number of components as well as the concentrations of the components in a product, expressed as 'H', which is the average number of binary separation steps needed to obtain any material from the mixture (i.e. the product). For a simple product consisting of a single material only (e.g. a glass bottle), H is zero. H is therefore proportional to the complexity of the product. For instance, automobiles contain many materials and are thus more complex, so they therefore have a very high value of H. However, this graph does not indicate the actual recyclability via liberation of items by manual, mechanical or thermal processing means. Initial complexity is one thing, but the ability to liberate material is another, more critical feature.

Source: Dahmus & Gutowski (2007). What gets recycled: an information theory based model for product recycling. *Environmental Science & Technology* 41: 7543–7550.

Recycling rates depend both on the degree of mixing and on the concentration of the target material or element. In a study of 60 metals (*Figure 3.14*), only one third have recycling rates greater than 50%. These include aluminium, titanium, chromium, manganese, iron, cobalt, nickel, copper, zinc, rhodium, palladium, silver, platinum and gold, all of which are either used in high concentrations and/or have a high value. Although more than half the metals have very low recycling rates of less than 1%, many of them are regarded as 'critical materials', including indium and gallium, or are rare earth metals including lanthanum, cerium, praseodymium, neodymium, gadolinium and dysprosium. These metals are all used in a wide range of electronic products including screens, chips and speakers and microphones and also in the magnets that are critical in many renewable energy technologies. The problem with recycling these critical metals is that the concentrations are often very low while the degree of mixing with other elements is very high. A major challenge moving forward is to ensure that design for dismantling and design for recyclability is prioritized in these rapidly growing industrial sectors.

Figure 3.14 End of life recycling rates for 60 metals



Notes: The figure uses the periodic table to show the global average end-of-life (post-consumer) functional recycling for sixty metals. Functional recycling is recycling in which the physical and chemical properties that made the material desirable in the first place are retained for subsequent use. Unfilled boxes indicate that no data or estimates are available, or that the element was not addressed as part of the study. These evaluations do not consider metal emissions from coal from power plants.

Source: UNEP (2011b). *Recycling Rates of Metals: A Status Report.* http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf

The presence of hazardous components is particularly important: for recycling to be economically feasible, recycling streams should ideally be contaminant free. Household hazardous waste (e.g. spent batteries), if not segregated, can contaminate the organic fractions and result in compost that is contaminated by toxic heavy metals.[51] Another example is that of waste paper containing polychlorinated biphenyls (PCBs), a persistent organic pollutant (POP) that is released when some older carbonless copy papers are recycled. A 2014 study on paper and board collected from Danish household waste suggested presence of measurable quantities of PCBs that could potentially have health and environmental consequences.[52]

51 Velis & Brunner (2013)

52 Pivnemko, K., E. Eriksson and T.F. Astrup (2014). Polychlorinated biphenyls (PCBs) in waste paper from Danish household waste. 5th International Conference on Engineering for Waste and Biomass Valorisation, Rio de Janeiro, 25-28 August 2014. Despite being banned since 1993, measurable levels of PCBs were found in wastepaper samples.

Segregation at source

Segregation of MSW at source is critical to ensure that the waste is separated into organic and dry recyclable fractions. Segregation of MSW at source, by separating organic and dry recyclable fractions, is critical to avoid cross-contamination and to maintain the quality of the materials, which will lead to more effective recycling and divert waste from landfill. Further, segregated waste reduces health and safety related risks to waste pickers and to the ecosystems around the waste treatment and disposal sites.

Despite the advantages of segregation, source separation prior to recycling is of relatively recent origin in formal MSW management systems. Referring back to *Figure 3.13*, the high recycling rates in high-income countries are now almost all based on segregation at source, resulting in relatively clean fractions being collected for recycling. Some examples of the use of such systems in middle-income countries are shown in *Box 3.4.*

BOX 3.4 EXAMPLES OF SEGREGATION INFRASTRUCTURE AS PART OF FORMAL SWM SYSTEMS

Separate collection of food waste, Yangshuo, PRC

Separate collection of plastics in Siddhipur, Nepal

Recycling containers in Phitsanulok, Thailand

Recycling containers in Benalmadena, Spain

Waste Segregation in Oslob, Cebu, Philippines

The informal recycling that is often dominant in many developing countries is generally from mixed MSW, although there can be a significant contribution from 'itinerant waste buyers', who collect and pay for source separated materials accumulated by householders or domestic servants. Community initiatives may also collect source-separated materials to raise funds for local charities.[53] Increasing segregation at source is a critical component of any programme to include the informal sector into mainstream waste management and would both improve their working conditions and improve their livelihoods by improving the quality of the recycled materials.[54]

Persuading citizens to segregate their MSW at source and to present it separately for collection requires a focus on changing behaviours.[55] Building design is also important, in order to ensure adequate space to store several separated fractions pending collection.

3.5.3 Technologies for resource recovery

A number of technologies are used for the processing and recovery of resources from waste. A summary for material separation technologies, including MRF, sorting centres and MBT is provided in *Box 3.5*, for organic recovery, including composting, anaerobic digestion and animal feed in Box 3.6 and in *Box 3.7* for energy recovery technologies. A complementary broad comparative analysis of some of the technologies that are commonly used, focusing on MSW, is presented in *Table 3.1*. This comparison is only indicative, addressing various elements such as applicability, advantages, relative costs and key factors for success. A listing of key resource materials to obtain more details of each technology is provided in Annex A, Further Resources.[56]

The selection of technologies appropriate to a particular local situation is as much of a governance issue as a technical matter: a key starting point is the waste composition and resultant waste properties, which need to be considered alongside local governance issues and the goals of the waste strategy. Selection of technologies is thus discussed later in the GWMO both under strategic planning (*Section 4.2.2*) and how to select an appropriate set of policy instruments that will be most effective in a particular situation (Section 4.9.2), where *Box 4.37* explicitly considers the selection of appropriate technologies for a developing country.

Emptying underground waste containers, Netherlands

53 An example is the city of Salem in Tamil Nadu, India. One kg of plastic waste is exchanged for a pencil, and 10 kg for a notebook. The community in turn sells plastic at Rs 2.50/kg to the market. Jars are kept outside city temples where worshipers are encouraged to bring used glass bottles. Glass is then sold at Rs 0.5/kg and the money collected is used to whitewash the temples.

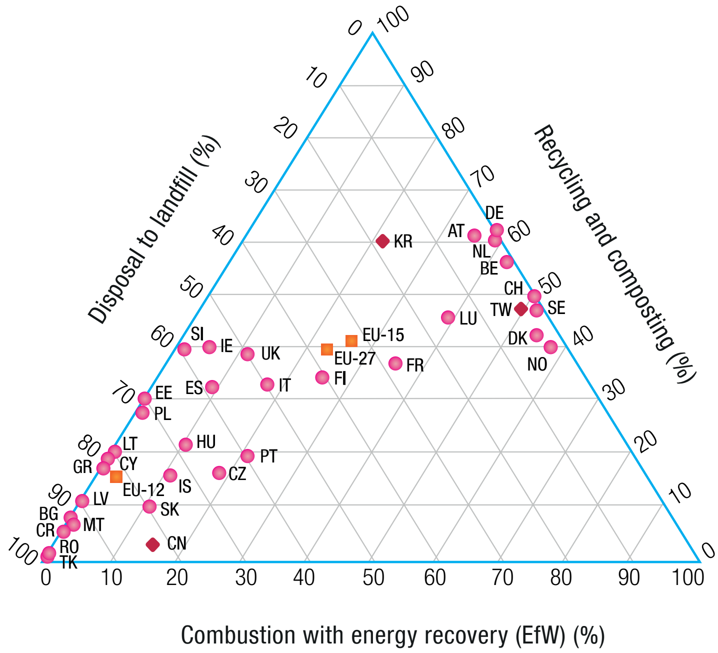
54 See Section 4.7 on Including stakeholders and Topic Sheet 14 on the informal waste sector.

55 See Section 4.5 on Economic instruments Figure 4.4 on the '4Es' framework for designing behaviour change initiatives.

56 See Annex A, Chapter 3, Technologies for resource recovery.

Figure 3.15 uses a triangle chart to show the percentages of disposal sent to landfill, recycling and composting, and combustion with energy recovery from waste (EfW) in different countries. Countries can be grouped into two main clusters: in one, rates of disposal to landfill range from 50 to 100%, with (collection for) recycling rates of 0 to 40%; in the other, rates of disposal to landfill are less than 10%, with both recycling and EfW in the range of 30 to 70%.

Figure 3.15 Proportions of recycling and composting, energy from waste (EfW) and disposal to landfill in European and non-European countries



Notes: Proportions of collection for recycling and composting, combustion with energy recovery (EfW) and disposal to landfill in European countries (circles) and non-European countries (rhombuses), along with European averages (cubes), in 2011.

Source: Bartl (2014). Moving from recycling to waste prevention: A review of barriers and enables. *Waste Management & Research.* 32(9) Supplement 3–18

Separation of wastes in an MRF/MBT plant in Madrid, Spain

BOX 3.5 ALTERNATIVE TECHNOLOGIES FOR RESOURCE RECOVERY FROM WASTE

(1) MATERIALS RECOVERY AND SORTING FACILITIES, INCLUDING MBT

Material recovery facilities (MRFs)

- *'Clean' MRFs*. 'Clean' material recovery facilities further separate clean, source-segregated dry materials for recycling and/or produce a prepared fuel. They may use either hand or automated sorting systems, or some combination of the two. They are used extensively in developed countries alongside source separation of mixed recyclables.
- *'Dirty' MRFs*. 'Dirty' material recovery facilities accept mixed waste (MSW or from other sources), from which dry recyclable materials are separated out from the organic fraction. These can be similar to the mechanical part of an MBT plant. Cross contamination results in lower quality outputs. These are more common than clean MRFs in developing countries.
- *Specific purpose MRFs*. Specialized material recovery facilities focus on specific waste streams, such as e-waste, C&D waste, or plastic waste.

Waste sorting centres

- *Waste sorting centres*. 'Waste sorting centre' is the term used mainly in developing countries to cover a range of options. For example, the city of Pune city in India has set up a number of mainly manual waste sorting centres with the informal sector to integrate them into the mainstream waste management system. Centres which involve the informal sector but use a mix of manual and mechanical sorting are common in Brazil and some other countries. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) has been promoting decentralized and Integrated Resource Recovery Centres (IRRC) in seven secondary cities across five countries in the Asia-Pacific region as a demonstration project.[57] In practice, waste sorting centres may overlap with MRFs, and in the case of IRRCs, with MBTs (explained below).

Mechanical biological treatment facilities (MBTs)

- Mechanical biological treatment facilities use a group of technologies and accept either MSW, or residual MSW after source separation of recyclables. MBTs are extensively used, particularly in Europe.
- MBTs use a range of combined mechanical and biological processes to treat and further separate the waste into recyclable, organic-rich and fuel-rich fractions. Each facility is designed with a particular purpose, using a specific input waste stream to prepare outputs to meet certain specifications. All can separate dry recyclates and/or refuse-derived fuel (RDF).
- Aerobic biological unit processes may be used to 'stabilize' the organic fraction to reduce its biodegradability, and therefore its capacity to generate methane, as a pre-treatment prior to landfill ('biostabilization' being the simplest option). Similar, but more complicated, is the production of compost-like output (CLO) for low-value on-land applications.
- A high-value configuration is to use biodrying (aerobic decomposition with high aeration) along with extensive mechanical processing to prepare a quality-controlled manufactured fuel (solid recovered fuel, or 'SRF'). This is particularly useful for treating high moisture organic wastes. SRF can be stored and transported for use by industry in thermal processing energy generation facilities (see 'Co-combustion in an industrial facility' in *Box 3.7* below).
- Anaerobic biological unit processes (or anaerobic digestion, AD) can produce biogas from the mechanically separated organic fraction of MSW.
- As the input to MBT plants is mixed waste, most of the solid outputs – including low-quality RDF and CLO – are all still regulated in most high-income countries as waste, so the products can only be used if the receiving facility or site obtains a waste management licence. Some higher quality SRF fuels, as well as dry materials separated for recycling, may be able to meet an 'end-of-waste' protocol so that the material can be traded as a product, and the using facility will then not require a waste management licence.[58]

57 See Box 4.5 in Section 4.2.2. Also see Storey et al. (2013), listed in Annex A, Chapter 3, Technologies for resource recovery.
58 See Sections 4.3.2 and 4.3.5. Italy was the first country to adopt an end-of-waste protocol for SRF.

BOX 3.6 ALTERNATIVE TECHNOLOGIES FOR RESOURCE RECOVERY FROM WASTE

(2) ORGANICS RECYCLING/RECOVERY

Composting

- Compost is the output of a biological process that converts biodegradable waste to a humus-like material. The principal use is to improve soil quality, as compost improves its biological and physical properties, for example enhancing water retention and resistance to erosion, which is particularly valuable in arid climates. It also has some value as fertilizer.
- Composting is applicable to a wide range of organic wastes. Residence times are typically longer for lignin-rich, 'hard', woody wastes.
- Contamination of compost due to household hazardous waste is an issue. In developed countries, regulations allow the use of waste-derived composts for food production, only if clean source-separated feedstock is used. Such materials may be able to meet an end-of-waste protocol.[59] This is the reason for the use of the term 'compost-like output' (CLO) when mixed waste is used as the feedstock (such as from an MBT plant). This will remain a 'waste' and be restricted to non-food applications at sites which obtain a license as waste facilities.
- Composting requires good process control, to ensure sufficient temperature and retention time to eliminate pathogens and to destroy weed seeds. Open heaps or windrows is the simplest and cheapest method. In-vessel composting uses a variety of proprietary technologies, which claim faster processing times and must be used (including under EU regulations) if the feedstock contains animal by-products. However, open-air or covered windrows are often used for the maturation of the output from in-vessel units.
- Typically 50 to 70% by weight of the MSW generated in developing countries is organic materials suitable for composting. Composting can be facilitated through segregation at source. Decentralized composting systems have been found to work well in many cities in low- and middle-income countries.[60] Home composting is also widely practised all around the world. Vermicomposting, which uses worms, is a popular option,[61] particularly in India.

Anaerobic digestion

- Anaerobic digestion (AD, also known as biomethanization) is considered a reliable source of energy in the form of biogas. AD works best for wet wastes, so is most widely used for sewage sludge and for livestock wastes. In 2013, the majority of the 13,800 AD plants in Europe and the 2,200 AD plants in the US treated those two types of waste.
- In developing countries, AD is widely applied at both the small and the community scale, for domestic or community use of the bio-gas. For example, in 2013 there were more than 40 million AD plants in the PRC, nearly 5 million in India and 300,000 in Nepal. [62]
- Application of AD to MSW is challenging. The high solid content, large particle size and inhomogeneous nature of the waste makes process control difficult.[63] It is particularly difficult to apply AD to lignin-rich, woody wastes. The digestate remaining can in principle be used as a soil conditioner. This usually requires a relatively long maturation (composting) stage prior to application to land.
- Contamination can both disrupt the AD process as well as make the digestate unsuitable for use as a soil conditioner. For MSW, the use of clean source-segregated feedstock is preferable, and essential if the (composted) digestate is to meet end-of-waste criteria and be used for food production. For an organic fraction separated mechanically from either mixed MSW or from residual MSW, such as from an MBT plant (see *Box 3.5*), contamination is a major issue. The digestate can subsequently go through a composting (maturation) step and be used as a compost-like output (CLO) for low-value on-land applications or be dried for use as a low calorific value RDF. RDF, CLO and digested sewage sludge will typically remain as 'wastes'. This means that all handlers and users need to obtain waste management licences.

Animal feeding[64]

- For clean, source-segregated food waste, direct reuse as animal feed is an important option.
- Japan makes extensive use of this option, using central processing plants to sterilize the waste to destroy any pathogens which may carry animal diseases.[65]

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59 See Topic Sheet 12 for examples of compost quality protocols in selected EU countries.
60 Eawag/Sandec and Waste Concern (2006), listed in Annex A, Chapter 3, Technologies for resource recovery.
61 See http://vermicomposting.com/ and http://www.calrecycle.ca.gov/Organics/Worms/
62 REN21 (2014)
63 In Section 4.2.2 on waste planning, Box 4.3 provides an example of a failed investment in an AD plant, attributed to a failure to adapt the design to local conditions.
64 See Topic Sheet 11 on Food Waste, found after Chapter 3.
65 See Section 4.3.5, Box 4.8 for more information on food waste recycling in Japan through processing the waste into animal feed.

BOX 3.7 ALTERNATIVE TECHNOLOGIES FOR RESOURCE RECOVERY FROM WASTE

(3) FUEL AND ENERGY RECOVERY FROM WASTE STREAMS

Combustion with energy recovery as electricity and/or heat

- Combustion with energy recovery has been widely used for MSW for many years. This process has been used to destroy the hazardous components of many 'difficult' wastes (such as POPs) and produce renewable and carbon-neutral energy from the biogenic part of the waste (roughly 65% of MSW in high-income countries).
- This option requires a high level of process control and of gas cleaning. Modern plants can achieve very high environmental protection standards. If not performed correctly, there is the potential for generating air emissions of particulates, acid gases, metals and incomplete combustion products such as dioxins. The process must be controlled through multi-stage gas cleaning to meet high standards.
- This technology can achieve high levels of energy efficiency. The EU threshold for energy efficiency, using a policy formula considering conversion of waste to both electricity and heat, is 65%.
- Worldwide, an estimated 765 'energy from waste' (EfW) plants exist for MSW, with an annual capacity of 83 million tonnes. These include 455 plants in the EU, 86 in the US (2011-12) and 150 in the People's Republic of China (PRC; 2014).[66]
- A list of questions regarding suitability in a particular situation, particularly in a developing country where the waste may be of low calorific value and financial sustainability may be an issue, is provided in Box 4.37.

Co-combustion in an industrial facility

- A prepared fuel (e.g. a solid recovered fuel or 'SRF') can be used in a range of industrial facilities, including cement kilns, industrial boilers and power plants. Attention needs to be paid to emission controls in the user facility. Cement kilns are attractive here, as they operate at high temperatures and already have air pollution control systems in place. However, these may be typically of lower standards than purpose-built EfW combustion plants.
- Co-combustion in an industrial facility is widely used for prepared fuels from MBT plants, particularly quality controlled SRF, but also RDF.
- Many cement kilns have been adapted to accept a high calorific value fuel blended from liquid hazardous wastes. This practice is already widespread in developed countries and is becoming more so in developing countries like Brazil, Ecuador, Malaysia, Pakistan, the PRC, Sri Lanka, Tanzania and Vietnam. Most cement production worldwide is controlled by a small number of multinational companies who are well placed to transfer the technology.[67]
- Prepared fuel products need to be of a high and consistent quality if they are to meet end-of-waste criteria. Otherwise, handlers and users will need to obtain waste management licenses.

Gasification

- Gasification was developed for the more efficient recovery of energy from solid fuels such as coal, and to generate a synthetic gas for combustion or as a chemical feedstock. The lack of oxygen reduces the generation of products of incomplete combustion such as dioxins. Gasification is adapted to a range of biomass fuels and to wood wastes.
- Some technologies utilize an RDF or SRF product from MBT pre-processing of MSW.
- Commercial scale gasification of MSW and industrial wastes has been carried out since the 1990s in Japan and the Republic of Korea. A variety of proprietary technologies have been demonstrated at full scale in North America and Europe since the 1970s, but these have all faced both high costs and operational challenges.

Pyrolysis

- Thermal degradation in the complete absence of oxygen can produce a liquid fuel (but also gaseous flow and solid residues). This option is most suitable for feedstock with a high calorific value and low moisture content such as wood waste and plastic waste.
- Some technologies utilize an RDF or SRF product from MBT pre-processing of MSW, but this application is not yet in widespread use.

Landfill gas utilization

- Methane is produced in landfill sites through the decomposition of organic wastes under anaerobic conditions. Uncontrolled release of methane from landfills is a potential major contributor to greenhouse gas emissions. The migration and accumulation of methane may also pose an explosion and fire risk to the surrounding community.
- Landfill gas collection is thus a routine part of a controlled landfill operation. The gas may be utilized, either in a gas engine to generate electricity and/or heat, or it may be cleaned and the pressure increased for injection into a natural gas grid or for direct utilization as a transport fuel.
- Energy recovery from landfill gas has come to be widely implemented in developing countries through climate funding under the Clean Development Mechanism (CDM) of the Kyoto Protocol. This provided an important funding mechanism for many cities, as the payments made for carbon credits from a previous year paid for the current operating costs of the landfill site[68].

66 Planning Commission of India (2014)
67 Huang et al. (2012)
68 See Section 5.7.6 on other revenue sources as well as the Philippines case in Section 1.1, Box 1.1. Also see Terraza & Willumsen (2009) and USEPA/ISWA (2012).

Table 3. 1 Technology sheet: Comparing technologies for resource recovery from MSW

<table>
<tr><th>TECHNOLOGY</th><th>COMPOSTING</th><th>ANAEROBIC DIGESTION (AD)</th></tr>
<tr><td>What is it?</td><td>Aerobic decomposition of organic wastes.</td><td>Biodegradation of (readily degradable) organic wastes in the absence of oxygen, with anaerobic microorganisms.
‘Wet’ or ‘dry’ variations.</td></tr>
<tr><td>Selling points?</td><td>Addresses organic fraction, which is a large percentage of MSW. Produces compost with value as soil improver and fertilizer. Completes biological material cycle.</td><td>Able to handle wet waste.
Produces biogas for direct use after upgrading, or for conversion to electricity/heat.</td></tr>
<tr><td rowspan="2">Input wastes</td><td colspan="2">Separated organic fraction of MSW, or food waste, e.g. from restaurants and canteens.</td></tr>
<tr><td>Other solid organic waste.
Can treat material high in lignin (woody).</td><td>Animal/human excreta. Liquids and sludges. Less suitable for high in lignin (woody) material.</td></tr>
<tr><td rowspan="2">Main outputs and their markets</td><td>Compost.
Serves as soil conditioner, mitigates erosion and is used in land reclamation and as a final cover for landfills.</td><td>Biogas.
Digestate can be composted for use as soil conditioner.
Digestate can be dewatered and used as low calorific value RDF.</td></tr>
<tr><td colspan="2">Use as a soil conditioner depends on control of inputs and the process, and regulatory permits. In food production, MSW-derived outputs can often only be used when the inputs were source-separated organic fractions.</td></tr>
<tr><td>Volume reduction (%)[1]</td><td>50-70%</td><td>45-50%</td></tr>
<tr><td>Sophistication of pollution control required</td><td>Low-medium</td><td>Low-medium</td></tr>
<tr><td>Cost per tonne (USD)[2]</td><td>25-70</td><td>65-120</td></tr>
<tr><td rowspan="2">Conditions for success</td><td>Temperature sensitive.
Long residence time.
Regular aeration required.
Odour control.</td><td>Good process control – microbial processes can easily be disrupted.
Works best with clean, homogeneous and consistent inputs – so MSW a difficult feed</td></tr>
<tr><td colspan="2">Clean input material; market for compost/digestate; contamination sensitive</td></tr>
<tr><td>Appropriate scale of plants</td><td>Household (home composting) and community (backyard, vermicomposting).
Centralized level, large-scale (windrow, aerated static pile, in-vessel).</td><td>Decentralized small scale digesters, including on-farm
Larger scale for the organic fraction of MSW.</td></tr>
<tr><td>Extent of use</td><td>Widespread in high-income countries.
Asia has a long tradition of making and using compost.</td><td>Widespread mainly for non-MSW.
Increased interest in high income, and for small scale low-tech in low-income, countries.</td></tr>
<tr><td>Applicability in developing countries[3]</td><td>High potential, particularly in developing countries with a high organic fraction in MSW.
Not yet widespread due to operating costs and need for source separation.</td><td>Small-scale anaerobic digesters are used to meet the heating and cooking needs of individual rural communities.</td></tr>
</table>

ENERGY FROM WASTE (EFW)			MECHANICAL BIOLOGICAL TREATMENT (MBT)
COMBUSTION WITH HEAT AND ENERGY RECOVERY	GASIFICATION	PYROLYSIS	
Direct combustion of waste in the presence of excess air (oxygen) to recover the energy content of the waste as heat energy, which can be used directly for heating or as a means of generating power (e.g. via steam turbine generators), or both (combined heat and power [CHP])	Partial oxidation of the wastes in the presence of less air (or other oxidant) than required for complete combustion.	Thermal degradation in the complete absence of air or other oxidizing agent	Combination of mechanical processing with biological reactors in the same plant. Generic term for many different technologies. Bioreactors can be biodrying or composting or AD.
Produces electricity and/or heat, e.g. for district heating systems. Completely sterilizes, destroys organic com pounds including hazardous wastes. Main output is a sterile ash.	Theoretical capability to use syngas in much more efficient gas engines in comparison to boiler and steam turbine. Potentially lower emissions of pollutants.	Wastes can be readily converted into liquid fuel products.	Advanced management of material flows, versatility and modularity. Actual benefits depend on the type of MBT and the main outputs of the plant.
Mixed MSW or prepared fuel (RDF). Versatile with feedstocks, if they are combustible.	Prepared waste. More suitable for treating the RDF or SRF produced by MBT rather than MSW. Also applicable to a range of other relatively homogeneous organic waste, such as wood waste, agricultural residues, sewage sludge, and plastic waste.		Mixed MSW or after source separation of dry recyclables ('residual MSW').
Heat only, electricity only, or both (CHP). Energy efficiency ranges from up to 30% (electricity only) to up to 95% (CHP). Secondary products: Fe and non-Fe metals and aggregate recycling. Potentially also precious metals.	Synthetic gas (syngas). Further combustion or conversion to chemical feedstock.	Liquid fuel. Further combustion or conversion to chemical feedstock.	Depending on plant type: SRF, RDF, compost-like output (CLO), biogas, reduced biodegradability output for landfill ('stabilized biowaste') SRF can be used in cement kilns, industrial boilers and power plants. Also dry recyclables.
75-90%	90%	50-90%	Variable – depends on plant configuration
High	Medium	Medium	Low-medium (depending on legislative requirements)
95-190	95-190	95-190	20-70
Good process control. Market needed for steam/hot water. Cold climate with heat demand (hot climate with cooling needs is possible but less prevalent). Waste to be within the combustible area of the Tanner diagram.	Pretreatment of waste required for removal of non-combustible materials and feedstock homogenization. Less versatile that combustion EfW.		Market needed for outputs. Plant design to match process objectives. Not all plant configurations have a sufficient track record.
	Market needed for synthetic gas.	Market needed for liquid fuels.	
Centralized large scale is the more common and preferred option. Economies of scale allow for higher standards of emission control and higher energy efficiency.	Small, medium, and large scale configurations are available.	Small, medium, and large scale configurations are available.	Small, medium, and large scale configurations are available. Typically modular, more flexible than thermal processing.
Widely applied, with an established track record in Europe, Japan, the PRC and the US. Increased interest in rapidly developing economies.	Japan and the Republic of Korea have had commercial facilities for gasification of MSW for 20 years. Interest in Europe for small/medium scale.	Not widely established for MSW.	Very widespread in Europe. Strong interest around the world.
MSW often too wet to burn without auxiliary fuel. Recovering the costs of an MSW EfW plant in low- to medium-income countries is difficult.	Potential for wood gasification technology. India has one of the world's largest programmes for small gasifiers.	Low – not established yet, even in developed countries.	Configurations are available at different levels of cost and sophistication suitable for developing countries.

1 Volume reduction will vary widely with the specific technology used. The rough estimates here are compiled from a variety of literature sources.
2 Estimated total cost per tonne in USD (net of operation and investment costs, less revenues from resource recovery), depending on income of the country. Assumes centralized facilities on a moderately large scale. See Section 5.2.2, Table 5.1 for more on comparative cost data. Source: Pfaff-Simoneit (2013), listed in Annex A,
Chapter 5, General reading on financing and economics.
3 See Sections 4.2.2 and 4.9.2 on strategic planning and the selection of policy instruments. Also see Box 4.37 on selecting appropriate technologies.

3.5.4 Investment worldwide in waste processing technologies

This section presents data on the development of new waste treatment and recovery facilities around the world. It should be noted that these data include all active facility development projects over the 2-year period 2013 to 2014, including projects at all stages of development, from feasibility and planning through construction. The total project value of 309 billion USD overestimates the degree of investment, as not all of the projects will actually be built. However, the data are very useful in providing a sense of the size of the current facility development projects (average value of 113 million USD per project), and the relative levels of activity, by waste type, by technology type and by geographic region. A summary of some of the basic data is provided in the figures that follow.

Analysing facility development projects by waste type, MSW accounts for 28% of all the projects by value (85 million USD). Wood and plant biomass (largely agricultural and forestry wastes) and organic waste together account for another 35% of the total (see *Figure 3.16*). Looking at MSW in particular, *Figure 3.17* shows a breakdown by technology. The largest contributors are various waste-to-energy technologies, particularly combustion with energy recovery (EfW). In terms of distribution by geographic area, the UK and the US show major investments, accounting for 24% and 11% of global MSW investment activity by value respectively, while the most active developing countries are the PRC (10%) and India (5%).[69]

Figure 3.16 Percentage of total facility development projects values by feedstock type

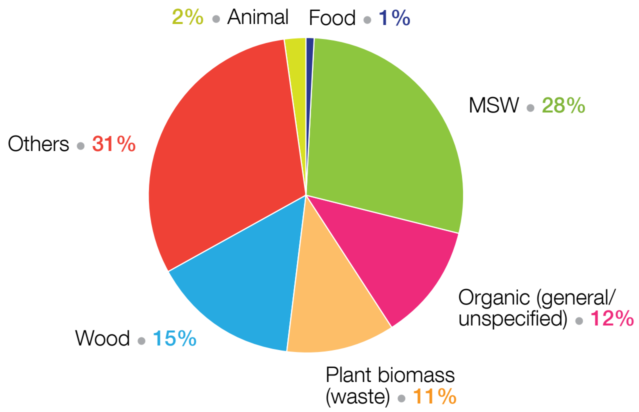
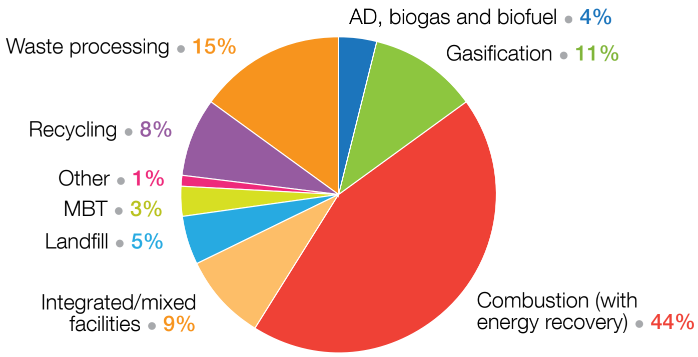


Figure 3.17 Percentage of total project values for MSW by facility type



Notes to Figures 3.16 and 3.17: Data covers 2723 facility development projects active between January 2013 and December 2014, across 93 countries in all. The total value across all projects was 309 billion USD, of which 85 billion USD was for MSW projects. The data cover all waste types, including agricultural and forestry (wood) waste and cover all technology types, but may favour larger, higher technology projects while underestimating others, such as activity in landfill investment. Average project value was 113 million USD. Projects at all stages of development, through feasibility, planning and construction, quality as 'active'. Therefore the figure for total active project value is higher than the ultimate amount invested.

Source: Extracted from AcuComm's Waste Business Finder database. http://acucomm.net/

69 For a discussion of the selection of appropriate technologies for developing countries in particular, see Sections 4.2.2 and 4.9.2 (*Box 4.37*).

3.6 GLOBAL SECONDARY MATERIALS INDUSTRY

The secondary materials industry has been important since the industrial revolution. Early in the 20th century, this industry relied mainly on relatively clean industrial waste, but the quantity of material separated from municipal solid waste has increased since the 1980s. This section focuses in particular on the transnational trade of this global industry.[70]

3.6.1 The globalization of secondary materials markets

Separation and collection for recycling only makes economic sense if the material is actually recycled, which depends on there being a market for the material. The waste industry depends closely on the secondary materials industry to provide that market. Some markets are relatively local, for example for compost as a soil conditioner or for aggregates from C&D waste. Others may be national or regional, such as for glass, processed fuels made from MSW (SRF may be more suitable for longer distance transport than RDF[71]) or wood waste. The focus in this section is primarily on those secondary materials which are globally traded commodities, including ferrous and non-ferrous metals, paper and board ('recovered paper' or 'recovered cellulose fibre'), plastics and textiles. The use of recycled materials competes with and displaces the use of primary materials and helps reduce the extraction of virgin material resources and reduce greenhouse gas emissions.[72]

In 2010, 700 to 800 million tonnes of "waste" were recycled as "secondary commodities",[73] derived from MSW as well as other waste streams. In terms of both tonnage and value, recycling markets are dominated by ferrous scrap (steel). In tonnage terms this is followed by paper and board, whereas in terms of value non-ferrous metals rank second, with aluminium and copper dominating this market. Based on the estimates made in Section 3.2, it appears that the main traded secondary materials represent around 10 to 15% of overall world waste generation, excluding construction and demolition, agricultural and forestry and mining and quarrying wastes.[74]

However, as reported below, only a relatively small proportion of the total 700 to 800 million tonnes (likely less than 25%) is traded across national boundaries. Asia makes up the most dynamic and arguably the most important global recycling market. Labour-intensive manufacturing industries and raw material extraction have been increasingly outsourced from developed to developing countries over a number of decades. The import of materials for recycling from high-income countries therefore represents an essential resource for fast-growing Asian economies, such as India, Indonesia, the PRC, Thailand and Turkey. Developing regions of Asia have relatively low labour and operating costs for industry, have different manufacturing quality standards and sometimes not so stringent environmental regulations compared to developed countries such as EU, the U.S., Canada and Japan, so the trend is not without its downside. The PRC is slowly beginning to raise its environmental standards, for both industry in general and the waste processing and recycling sectors in particular. As the costs of meeting environmental compliance are high in developed countries, there are potential large profits to be made from following what has been described as the 'least environmental pathway',[75] by exporting wastes to developing countries with lower levels of control and enforcement. This can be done either illegally for simple dumping, or possibly legally for recycling, but without proper controls on public and occupational health and environmental pollution. The latter applies to some extent to the global market for recycled commodities such as plastics and paper, and arguably even more so for some hazardous wastes, including e-wastes and end-of-life ships.

Perhaps the most notable characteristic of secondary material markets is their price volatility. Secondary materials have traditionally been used to 'top up' a relatively stable supply of primary materials (made from virgin raw materials) in response to short-term variations in market demand, so their prices have tended to be even more volatile than those of the related primary commodities. Both primary and secondary material prices appear to be increasing in volatility: data are provided in *Figure 5.1* in Chapter 5. For example, major price

70 See Sections 2.3 on drivers for waste and resource management and 5.3.3 on the resource recovery business.
71 An example of a regional market for a minimally-processed RDF is the rise in exports from the UK to the Netherlands, Germany and Sweden after 2010 - the trade rose from 0 to more than 2 million tonnes per annum, driven both by a rise in landfill tax in the UK and by surplus capacity in European EfW plants, which needed to meet long term contracts for heat and power. See also Case Study 6 on energy from waste. http://www.ciwm.co.uk/CIWM/MediaCentre/Current_pressreleases/Press_Releases_2013/ciwm_news_310713.aspx
72 See Topic Sheet 1 on waste and climate, following Chapter 1.
73 Bureau of International Recycling (2010, 2011). World Markets for Recovered and Recycled Commodities. See Annex A, Chapter 3, Global secondary materials industry.
74 10 to 15% is an underestimate of total recycling, as it is selective in the listing of recycled materials (for example, it excludes organics recycling), but more comprehensive in its inclusion of waste types.
75 Crang et al. (2013) and Velis (2015). See also Sections 4.3.7 and 5.3.4 for a discussion of waste trafficking and waste crime.

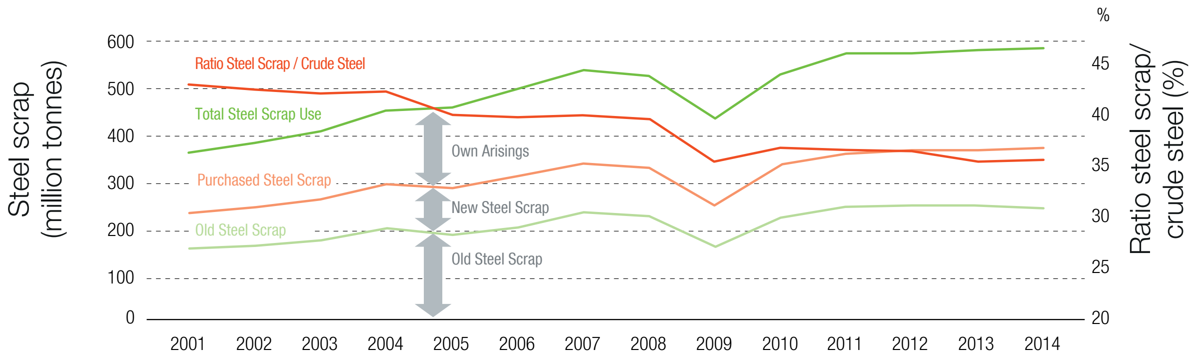
crashes occurred during the world recession of 2009 and due to the slump in oil prices late in 2014 and early in 2015. Such market instability is a major threat to the sustainability of recycling programmes around the world.

Widespread trade in materials recovered from waste depends on the materials being classified as no longer being waste, so that they can be traded freely as a product without the need for handlers and users to obtain waste management licences.[76] The EU is in the process of developing 'end-of-waste' criteria or protocols, with criteria already defined for iron, steel and aluminium scrap, and under preparation (2015) for copper scrap, recovered paper, glass cullet and biodegradable waste/compost.[77]

3.6.2 Ferrous metals

World production of iron and steel is rising steadily, increasing by 40% from 2005 to reach over 1.67 billion tonnes in 2014. According to the industry, every tonne of ferrous metal scrap that goes back into production reduces the use of iron ore by 1,400 kg, of coal by 740 kg, and of limestone by 120 kg.[78] *Figure 3.18* shows a steady increase in scrap use from 2001-2014, although this has not kept pace with steel production, as the ratio of steel scrap to crude steel has steadily decreased over the period. By 2011-2014, total steel scrap use was approaching 600 million tpa, representing rather less than 40% of total steel production. Scrap can be grouped into the three sources of (i) post-consumer (old) scrap; (ii) new scrap (e.g. production off-cuts) purchased by steel mills from industrial users; and (iii) own arisings, directly recycled within the steel mills. The quantities of both new and own scrap are relatively stable, with the quantities of old scrap varying over the 14 years between 180 and 260 million tonnes per annum (*Figure 3.18*). Scrap is the main raw material for electric arc furnaces, while it can only be used as a small percentage of the total feedstock for traditional blast furnaces using coke and iron ore.

Figure 3.18 The use of steel scrap for steelmaking (global totals)



Notes: Figure shows time series data for steel scrap. New scrap is scrap from steel processing and old scrap is from products after their use. Own arisings are rejects from melting, casting and rolling.

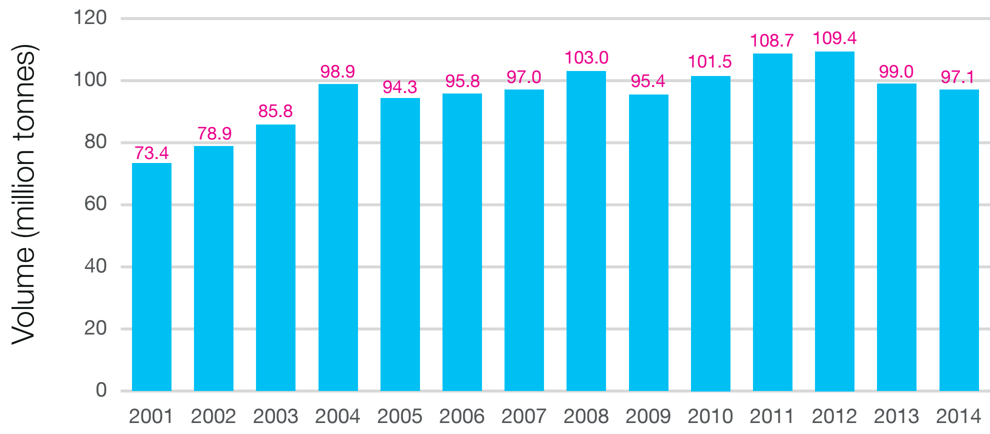
Source: Bureau of International Recycling (2015). World Steel Recycling in Figures 2010 – 2014. http://www.bir.org/publications/brochures/

External trade across national boundaries accounts for less than 20% of total steel scrap usage (*Figure 3.19*), but increased in tonnage terms from 73 million tonnes in 2001 to around 100 million tonnes from 2004-2014. Excluding trade within the EU, the major importer in the period from 2010 to 2014 was Turkey (about 30% of the total trade outside of the EU); Turkey is unusual in using electric arc furnaces for around 70% of its steel production, and relying on scrap for around 90% of its raw materials. Other significant importers include India (10%), the People's Republic of China (7%), the Republic of Korea (14%) and Republic of China (7%). Imports to these Asian countries account for two thirds of external trade outside of the EU. Other significant importers

76 See Sections 4.3.2 on legal classifications and 4.3.5 on legislation for resource recovery.
77 http://ec.europa.eu/environment/waste/framework/end_of_waste.htm. 'End-of-waste' criteria are the conditions that need to be met for materials to no longer be classified as 'waste' but rather as a 'product' or a 'secondary raw material.' Box 4.9 in Chapter 4 shows examples of existing protocols for compost in several EU countries, and Topic Sheet 12, found after Section 4.3.5, shows how end-of-waste can be implemented in practice for compost.
78 World Steel Association (2012). Figures based on blast furnace production.

are the U.S., EU, Indonesia, Malaysia, Canada and Thailand. The dominant exporters are the US (about 28%), the EU (25%) and Japan (12%). Russia's share of the export market fell from around 20% in 2005 to 4% in 2010 but had risen again to 9% in 2014. Other significant exporters were Canada, Australia and South Africa.

Figure 3.19 Volume of external global steel scrap trade



Notes: Figure shows temporal data for the external trade in steel scrap.

Source: Bureau of International Recycling (2014, 2015). World Steel Recycling in Figures 2009 – 2013 and 2010 – 2014. Available from http://www.bir.org/publications/brochures/

3.6.3 Non-ferrous metals

Global production of the main non-ferrous metals is rising fast, as is demand for scrap for recycling (*Table 3.2*). The prices of these commonly-used metals are relatively high, so scrap is in heavy demand. However, as shown earlier in *Figure 3.14*, it is only for 20 out of 60 metals that more than half is recycled when products reach their end of life.

Aluminium is both the most heavily used and the fastest growing of the non-ferrous metals, so that is taken as an example here. The story is dominated by the PRC. In 2000, the PRC produced 2.9 million tonnes of aluminium (12% of the global total); by 2011, this had risen to 19.4 million tonnes (43% of a global total which had grown by 80%). As shown in *Figure 3.20*, of the 7.4 million tonne per annum increase in demand for aluminium scrap over the same period, the PRC accounts for 6.3 million tonnes (85%); consumption also increased in the rest of Asia and in Europe, but decreased in the US. Despite the increase in scrap consumption, supply from scrap has failed to keep pace with the increase in aluminium production: the ratio of scrap used in aluminium production has fallen slightly over the period from 31 to 29%.

As with steel, only a proportion of aluminium scrap is traded externally across national boundaries. *Figure 3.21* shows that quantities have increased fourfold from 2000, reaching around 4 million tonnes (around 20% of the total) in 2011. The PRC accounts for 60% of imports and the rest of Asia 30%, while most exports originate in North America and Europe.

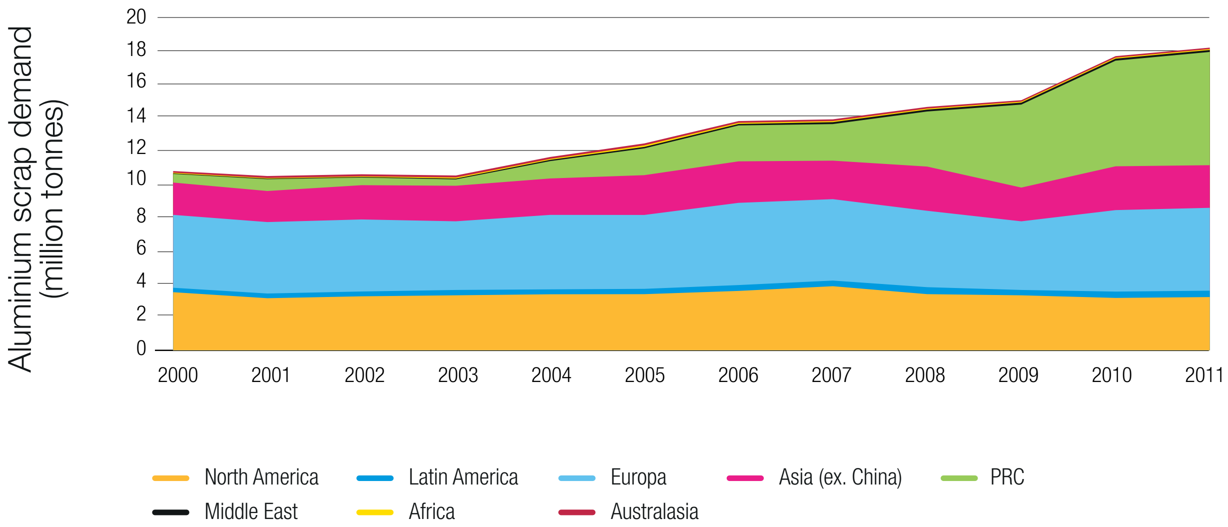
Table 3.2 Global demand for the largest volume non-ferrous metals and global scrap consumption

COMMODITY	GLOBAL DEMAND FOR METAL*			GLOBAL SCRAP CONSUMPTION		
	2000 (Million tonnes)	2011 (Million tonnes)	Percentage growth 2000-2011*	2000 (Million tonnes)	2011 (Million tonnes)	Percentage growth 2000-2011
Aluminium	25	45	82%	11	18	68%
Copper	15	19	30%	7.0	10	45%
Lead	9	12	30%	3.7	5.8	57%
Zinc	7	10	40%	0.8	1.1	34%
Nickel	1	1.1	10%	0.6	0.9	42%
Steel	1144 (2005 data)	1607	(40%)	401	573	43%

Notes: Global demand for primary metal has been rising quickly, as has global scrap consumption. The last row for steel is shown for comparison. The non-ferrous metal tonnages are 35 to 1,000 times lower.

Source: Bureau of International Recycling (2011). Global non-ferrous scrap flows 2000-2011. Available from http://www.bir.org/publications/brochures

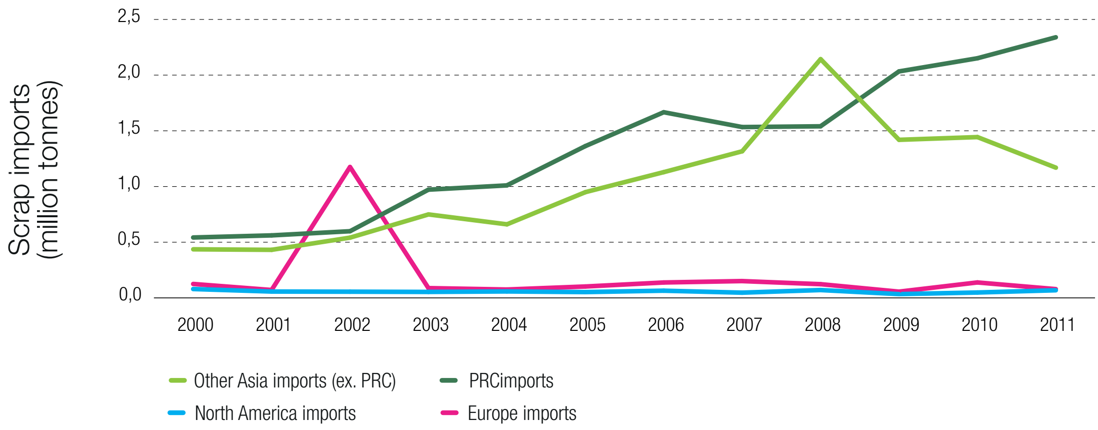
Figure 3.20 Global aluminium scrap demand from 2000-2011 by region



Notes: 85% of the increase is accounted for by the PRC, with the rest of Asia and Europe also showing increases.

Source: Bureau of International Recycling (2014, 2015). World Steel Recycling in Figures 2009 – 2013 and 2010 – 2014. Available from http://www.bir.org/publications/brochures/

Figure 3.21 Aluminium scrap imports from 2000-2011



Notes: The total traded quantity has increased approximately fourfold, from around 1 million to around 4 million tonnes per annum. The largest increase is in the PRC, followed by the rest of Asia.

Source: Bureau of International Recycling (2014, 2015). World Steel Recycling in Figures 2009 – 2013 and 2010 – 2014. Available from http://www.bir.org/publications/brochures/

3.6.4 Plastics

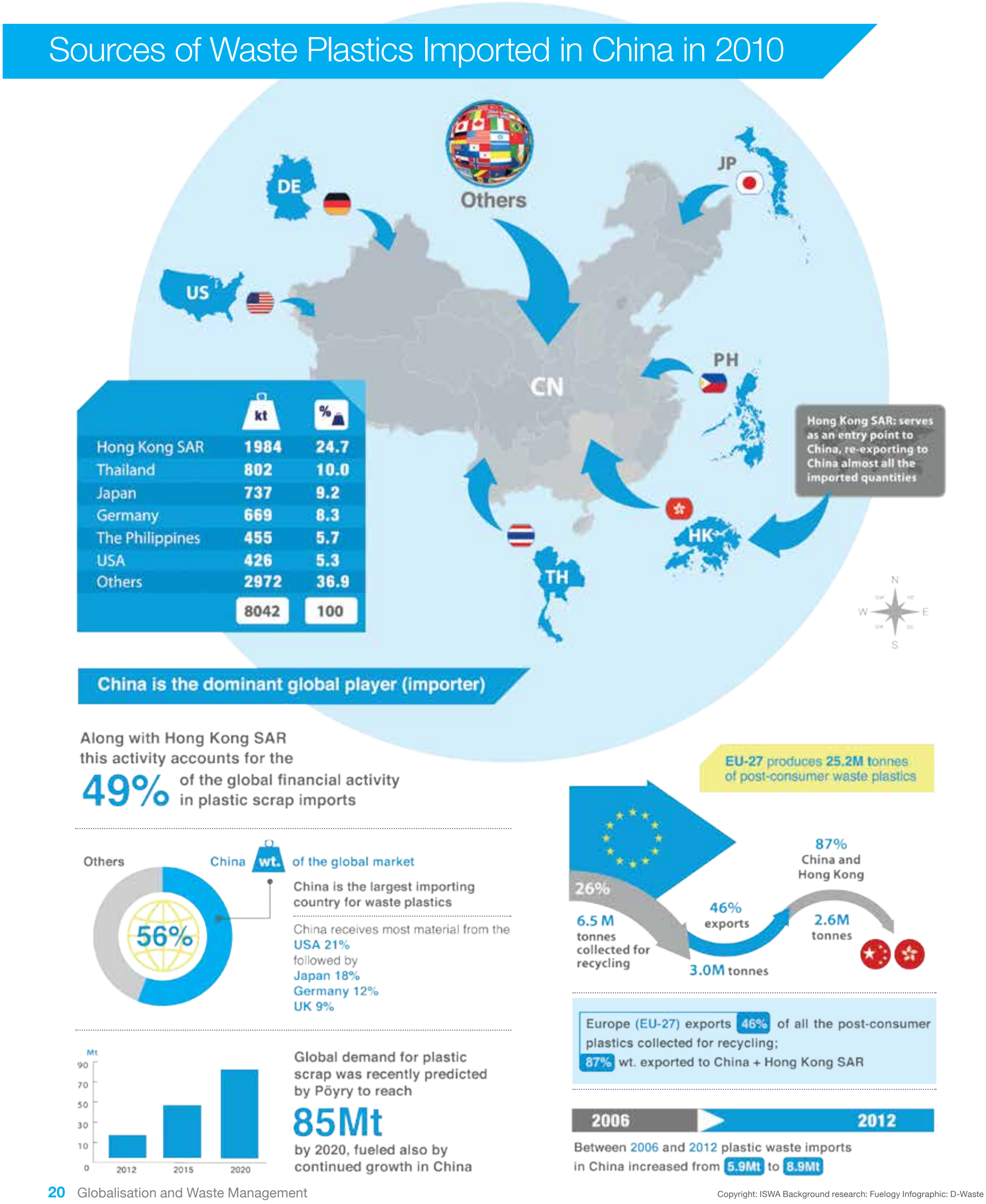
International trade in used plastics is prospering. With global production of plastics skyrocketing, from 1.5 million tonnes in 1950 to 204 million tonnes in 2002 and 299 million tonnes in 2013,[79] and a continuing shift of production from the West to Asia (more than 40% by weight of world production in 2013), the annual volume of transnationally traded waste plastics at 15 million tonnes represents just 5% by weight of new plastics production. Plastic scrap flows from Western countries with established recycling collection systems mainly to the PRC, which dominates the international market (see *Figure 3.22*), receiving around 56% wt. of global imports. Europe (EU-27) collectively exports almost half of the plastics collected for recycling, at least 87% of which goes to the PRC.[80]

Plastic scrap imports to the PRC increased from 6 million tonnes in 2006 to 8 million tonnes in 2011, but the domestic collection of plastics for recycling increased even faster, from 7 to 15 million tonnes over the same period. This is expected to rise further as domestic recycling rates increase. However, it is speculated that the poor quality of domestic post-consumer recyclates necessitates quality imports for capital-intensive better quality manufacturing, while the inferior imports and domestic recycled plastics end up at either low-tech, unregulated facilities and maybe also EfW plants. While the PRC government is actively working to increase the quality of imported plastics and reduce the numbers of unregulated facilities (as witnessed by the 2013-14 Green Fence Operation, as an example), the environmental benefits from plastic exports to the PRC are questionable given the dominance of uncontrolled reprocessing/manufacturing with very low environmental standards.[81]

A recent report[82] asked the question: Is dependence on a single importing country a risk to the exporting countries which need to meet high, statutory recycling targets for plastics? The conclusion drawn was 'Yes', from two perspectives. First, the PRC may in the medium- or long-term become self-sufficient in high-quality secondary plastics from domestic sources and may not import. Second, the aim of achieving high recycling rates in exporting countries such as the EU was to achieve sustainable resource recovery, meeting high standards of environmental protection and achieving clean material cycles and resource utilization; this is questionable when almost half of the plastics collected in the EU for recycling are exported to countries with lower environmental standards. The long-term solution likely requires a balance between developing domestic capacity within the EU for recycling and relying on international markets: for example, quality, segregated polymers, such as clean PET from bottles, are increasingly sought-after commodities on the global market, with manufacturers in the US, Europe and the PRC competing for a limited supply. At the same time, continuing efforts are required to ensure a 'level playing field' in terms of environmental standards.

79 http://www.plasticseurope.org/Document/plastics-the-facts-20142015.aspx?FolID=2
80 All of the data in this section is taken from Velis (2014a), listed in Annex A, Chapter 3, Global secondary material markets. Much of it is based on research undertaken by Sihui Zhou at Imperial College London in 2012.
81 Minter (2013).
82 Mavropoulos et al. (2014), listed in Annex A, Chapter 1, Waste management. Based on the detailed work of Velis (2014a).

Figure 3.22 Global flow of plastics to the People's Republic of China in 2010



Source: ISWA, reproduced directly from Velis (2014). Global recycling markets – plastic waste: A story for one player – China. Infographic prepared by D-Waste on behalf of International Solid Waste Association – Globalisation and Waste Management Task Force. ISWA, Vienna. http://www.iswa.org/fileadmin/galleries/Task_Forces/TFGWM_Report_GRM_Plastic_China_LR.pdf

3.6.5 Paper

Total world production of paper and paperboard in 2012 was around 400 million tonnes, of which 45% was in Asia, 26% in Europe and 21% in North America.[83]

Recycled paper and paperboard (known in the industry as 'recovered paper' or 'recovered cellulose fibre' (RCF) has always been a major raw material used in the paper industry. In 1990, recovered paper accounted for 40% of the total pulp used in the European paper industry, and by 2013 this had risen to 53%. At the same time total production in Europe had risen by around 50%.[84] This increase in 'recycled content' was driven mainly by the 'rediscovery' of municipal solid waste recycling and thus an increase in recovered paper supply, but the increase in MSW recycling rates from around 8% in 1990 to approaching 50% in 2012 meant that supply was outstripping regional demand.[85]


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Table 3.3 shows world collection and consumption of recovered paper by region, distinguishing those individual countries handling more than 1 million tonnes per annum. Total quantities are around 230 million tonnes. Of this, around 80% is consumed within the country where the paper is collected for recycling. All of the named countries in *Table 3.3* consume more than 1 million tonnes per annum of recovered paper in their national paper industry. Transboundary trade totals 40 to 50 million tonnes per annum. This trade is now dominated by the PRC, which despite collecting almost as much paper for recycling within the country (45 million tonnes per annum) as does the U.S., still imported a net quantity of 30 million tonnes in 2012. Other Asian countries, notably India and Indonesia, accounted for a further 8 million tonnes of net imports. Other net importing countries included Mexico, Austria, Germany, Sweden and Spain. The US accounts for 20 million tonnes of net exports, followed by Japan and the UK at 4 to 5 million tonnes each. The paper market is also influenced by regional variations in the availability and price of wood pulp, which is e.g. relatively lower in Latin America.


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Table 3.3 also shows that, although global trade in recovered paper has a long history, the quantities shipped around the world have increased rapidly over the last two decades, in response to both increased collections of MSW for recycling in Europe, North America and Japan, and to the rise of the PRC as the dominant world paper producer. Between 1997 and 2012, net exports from the US and Europe have risen around fourfold, as have net imports to the 'rest of Asia'; Japan has moved from being a small net importer to the second largest net exporter; and the PRC has increased its imports by a factor of 20.

Quality is likely to be key to the future of the global market for recovered paper. Since 2000, large paper companies in the PRC have either acquired or established paper merchants operating in high income countries, in order to increase their control over their recovered paper supply chain. The European paper industry has been making the case that the EU's end-of-waste criteria[86] for waste paper should be set 'high', to ensure that recovered paper delivered to paper mills is pre-sorted and of high quality.[87]

83 Most of the data in this section comes from the BIR 2014 report, Recovered Paper Market in 2012.
84 CEPI Key Statistics 2013 http://www.cepi.org/system/files/public/documents/publications/statistics/2014/Final%20Key%20statistics%202013.pdf
85 See Sections 2.3 and 5.5.1
86 'End-of-waste' criteria are the conditions that need to be met for materials to no longer be classified as 'waste' but rather as a 'product' or a 'secondary raw material.'
87 CEPI press release, 20 September 2013. http://www.cepi.org/topic/recycling/pressrelease/endofwaste

Table 3.3 Leading countries collecting & consuming recovered paper and regional totals (2012)

Unit: Million tonnes

Region		Country	Collections of recovered paper and board	Consumption of recovered paper	Net flows: positive = imports negative = exports	Regional total net flows 2012	Regional total net flows 1997
North America		United States	46.3	26.3	-20.0	-22	-6
		Canada	4.4	2.6	-1.8		
		Regional subtotal	*50.6*	*29.9*	-21.8		
Latin America		Brazil	4.5	4.5	0.0	**1**	
		Mexico	**3.9**	**4.8**	**0.8**		
		Regional subtotal	*12.2*	*13.1*	*0.9*		
Europe		**Germany**	**15.3**	**16.2**	**0.9**	-7	-1.6
		United Kingdom	8.2	3.8	-4.4		
		France	7.3	5.0	-2.3		
		Italy	6.2	4.7	-1.6		
		Spain	**4.6**	**5.1**	**0.5**		
		Netherlands	2.6	2.1	-0.4		
		Belgium	1.9	1.2	-0.7		
		Poland*	1.6	1.3	-0.3		
		Austria	**1.5**	**2.4**	**1.0**		
		Sweden*	**1.3**	**1.9**	**0.6**		
		Switzerland	1.2	1.0	-0.2		
		Russia	2.6	2.2	-0.4		
		Regional subtotal	*62.0*	*54.8*	*-7.2*		
Asia	**Japan**	Japan	21.7	16.8	-4.9	-5	**0.05**
	PRC	**PRC**	**44.7**	**75.0**	**30.3**	**30**	**1.6**
	Rest of Asia	**Republic of Korea**	**8.8**	**9.6**	**0.8**	**8**	**2**
		Indonesia	**3.6**	**5.9**	**2.3**		
		India	**3.4**	**5.7**	**2.3**		
		Republic of China	**3.1**	**3.8**	**0.8**		
		Thailand	**2.7**	**3.6**	**1.0**		
		Malaysia*	**1.2**	**1.6**	**0.4**		
		Turkey*	**1.0**	**1.1**	**0.1**		
		Regional subtotal	*99.4*	*130.9*	*31.5*		
Australasia		Australia*	3.4	2.0	-1.4	-1	
		Regional subtotal	*3.5*	*1.9*	*-1.6*		
Africa		South Africa*	1.0	1.0	0.0	0	
		Regional subtotal	*2.8*	*2.6*	*0.2*		
Totals		**Named countries**	**207.7**	**211.0**	**3.3**		
		World totals	**230.5**	**233.2**	**2.8**		

Notes: Unless otherwise noted, data for collection and consumption is for 2012, and is taken from the Bureau of International Recycling (BIR, 2014): Recovered Paper Market in 2012.

- 'Collections' shows national totals of recovered paper and board collected by the secondary paper industry.
- 'Consumption' shows national consumption of recovered paper by the paper industry (domestic deliveries plus imports)
- 'Net flows' shows national consumption less national collections: a positive figure denotes a net importing country (highlighted in bold); a negative figure denotes a net exporter. These figures do not total exactly zero, as some stocks are carried forward between years. Note that some countries may be both a significant importer and a net exporter. Examples include the Netherlands and Belgium, where the ports of Rotterdam and Antwerp handle exports on behalf of a number of countries.
- The BIR report provides data for most of the leading collecting and consuming countries in 2012. A few other countries collecting or consuming more than 1 million tonnes per annum, for which 2012 data are missing, have been added, using 2009 data from the FAO Recovered Paper Survey. These have been indicated with an asterisk.
- The regional sub-totals, taken from the BIR report, show data for all countries in the region, not just the named countries.
- The last two columns summarize net flows by region, using the 2012 data from the table. The 1997 data provided for comparison is taken from Kojima and Michida (2011). This is available only for selected regions, for which the definitions differ from those used for the 2012 data: the 'Europe' data is for the EU-15; the 'Rest of Asia' data is for the ASEAN-6 (Association of Southeast Asian Nations) countries of Brunei Darussalam, Indonesia, Malaysia, the Philippines, Singapore, and Thailand.

3.6.6 Textiles

Used textiles have become a globally traded commodity. Focusing on the second hand clothing economy in particular, this has doubled from 1.26 billion USD in 2001 to 2.5 billion USD in 2009. Textile recyclers sort clothing into reusable garments or recycling grades, the latter including industrial cleaning cloths and reclaimed fibres. The sector has globalized as a result of the growth of supply from the global North, the relocation of sorting operations to Eastern Europe and the global South, and the development of differentiated markets for reuse.[88]

Five high-income countries (Canada, Germany, Republic of Korea, UK and U.S.) account for more than half of all exports of second-hand clothing, most of it originating as donations to charity when it reaches the end of its perceived useful first life. Charities typically select only a small percentage for domestic reuse (estimated at 20% in the UK), often for sale in their own shops. The larger part is sold on to a complex network of global traders, being sorted many times into increasingly differentiated components. Major sorting centres are located in Poland, India and Ghana. Many of the higher quality garments are sold on in Eastern Europe. Lower quality wearable items from Europe and North America tend to go to Africa, while those from Asian countries tend to go to Asian markets (matching the clothing to the users body shape). Fifteen countries account for half of all imports: Angola, Benin, Cambodia, Cameroon, Canada, Germany, Ghana, India, Kenya, Malaysia, Pakistan, Poland, Russia, Tunisia and Ukraine Many of these countries are major re-exporters of sorted fractions.

3.7 OTHER WASTE STREAMS AND EMERGING ISSUES

Some waste materials are of particular interest due to their characteristics and generation patterns, or due to challenges in their management. Some of these are explored in a series of Topic Sheets through the GWMO, a number of which have been placed after Chapter 3. These cover for example construction and demolition waste; hazardous waste; e-waste; plastic waste and marine litter; disaster waste; and food waste.

It is safe to predict that a number of 'new' waste streams of concern will come onto the agenda over the next decade. One such emerging issue already on the horizon is nano-waste. The chemical-physical properties of nano-materials may pose risks to human health and the environment that are not yet entirely known or understood. The Federal Office for the Environment (FOEN) in Switzerland highlighted the risks in its Policy Paper on the Safe and Environmentally Sound Disposal of Nano-waste.[89] NANoREG is a research project funded by the EU that aims to develop a common European approach to the regulatory testing of nano-waste and other manufactured nano-materials.[90]

88 Chang et al. (2013), Norris (2013)
89 Swiss Federal Office for the Environment. Nanowaste. http://www.bafu.admin.ch/abfall/01472/12850/index.html?lang=en
90 See EU Framework 7 Programme, NANoREG. http://nanoreg.eu/

About the UNEP Division of Technology, Industry and Economics

Set up in 1975, three years after UNEP was created, the Division of Technology, Industry and Economics (DTIE) provides solutions to policy-makers and helps change the business environment by offering platforms for dialogue and co-operation, innovative policy options, pilot projects and creative market mechanisms.

DTIE plays a leading role in three of the six UNEP strategic priorities: **climate change, harmful substances and hazardous waste, resource efficiency.**

DTIE is also actively contributing to the **Green Economy Initiative** launched by UNEP in 2008. This aims to shift national and world economies on to a new path, in which jobs and output growth are driven by increased investment in green sectors, and by a switch of consumers' preferences towards environmentally friendly goods and services.

Moreover, DTIE is responsible for **fulfilling UNEP's mandate as an implementing agency for the Montreal Protocol Multilateral Fund** and plays an executing role for a number of UNEP projects financed by the Global Environment Facility.

The Office of the Director, located in Paris, coordinates activities through:

> **The International Environmental Technology Centre** – IETC (Osaka), which promotes the collection and dissemination of knowledge on Environmentally Sound Technologies with a focus on waste management. The broad objective is to enhance the understanding of converting waste into a resource and thus reduce impacts on human health and the environment (land, water and air).

> **Sustainable Consumption and Production** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.

> **Chemicals** (Geneva), which catalyses global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.

> **Energy** (Paris and Nairobi), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.

> **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.

> **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies. This branch is also charged with producing green economy reports.

DTIE works with many partners (other UN agencies and programmes, international organizations, governments, non-governmental organizations, business, industry, the media and the public) to raise awareness, improve the transfer of knowledge and information, foster technological cooperation and implement international conventions and agreements.

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The Global Waste Management Outlook, a collective effort of the United Nations Environment Programme and the International Waste Management Association, is a pioneering scientific global assessment on the state of waste management and a call for action to the international community.

Prepared as a follow up to the Rio+20 Summit and as a response to UNEP Governing Council decision GC 27/12, the document establishes the rationale and the tools for taking a holistic approach towards waste management and recognizing waste and resource management as a significant contributor to sustainable development and climate change mitigation.

The Outlook is primarily focused on the 'governance' issues which need to be addressed to establish a sustainable solution – including the regulatory and other policy instruments, the partnerships and the financing models. Broad in scope and global in coverage, the Outlook includes a series of Topic Sheets and case studies addressing specific issues and illustrating featured initiatives.

This document provides an inspiring possible way forward on waste management, drawing conclusions and making recommendations to assist policy makers and practitioners to develop local solutions for waste management. To complement the Sustainable Development Goals of the Post-2015 Development Agenda, the Outlook sets forth Global Waste Management Goals and a Global Call to Action to achieve those goals.

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