15

Urban Solid Waste Management

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Managing and Utilizing Solid Waste

Municipal solid waste (MSW) management is inextricably linked to increasing urbanization, development, and climate change. The municipal authority's ability to improve solid waste management also provides large opportunities to mitigate climate change and generate co-benefits, such as improved public health and local environmental conservation.

Driven by urban population growth, rising rates of waste generation will severely strain existing MSW infrastructure in low- and middle-income countries. In most of these countries, the challenge is focused on effective waste collection and improving waste treatment systems to reduce greenhouse gas (GHG) emissions. In contrast, high-income countries can improve waste recovery through reuse and recycling and promote upstream interventions to prevent waste at the source.

Because stakeholder involvement, economic interventions, and institutional capacity are all important for enhancing the solid waste management, integrated approaches involving multiple technical, environmental, social, and economic efforts will be necessary.

Major Findings

- Globally, solid waste generation was about 1.3 billion tons in 2010. Due to population growth and rising standards of living worldwide, waste generation is likely to increase significantly by 2100. A large majority of this increase will come from cities in low- and middle-income countries, where per capita waste generation is expected to grow.
- Up to 3–5% of global GHG emissions come from improper waste management. The majority of these emissions are methane – a gas with high greenhouse potential – that is produced in landfills. Landfills, therefore, present significant opportunities to reduce GHG emissions in high- and middle-income countries.
- Even though waste generation increases with affluence and urbanization, GHG emissions from municipal waste systems are lower in more affluent cities. In European and North American cities, GHG emissions from the waste sector account for 2–4% of the total urban emissions. These shares are smaller than in African and South American cities, where emissions from the waste sector are 4–9% of the total urban emissions. This is because more affluent cities tend to have the necessary infrastructure to reduce methane emissions from MSW.
- In low- and middle-income countries, solid waste management represents 3–15% of city budgets, with 80–90% of the funds spent on waste collection. Even so, collection coverage ranges from only 25% to 75%. The primary means of waste disposal is open dumping, which severely compromises public health.
- Landfill gas-to-energy is an economical technique for reducing GHG emissions from the solid sector. This approach provides high potential to reduce emissions at a cost of less than US$10 per tCO_2-eq. However, gas-to-energy technology can be employed only at properly maintained landfills and managed dumpsites, and social aspects of deployment need to be considered.

Key Messages

Reducing GHG emissions in the waste sector can improve public health; improve quality of life; and reduce local pollution in the air, water, and land while providing livelihood opportunities to the urban poor. Cities should exploit the low-hanging fruit for achieving emissions reduction goals by using existing technologies to reduce methane emissions from landfills. In low- and middle-income countries, the best opportunities involve increasing the rates of waste collection, building and maintaining sanitary landfills, recovering materials and energy by increasing recycling rates, and adopting waste-to-energy (WTE) technologies. Resource managers in all cities should consider options such as reduce, re-use, recycle, and energy recovery in the waste management hierarchy

15.1 Introduction

Municipal solid waste (MSW) management is inextricably linked to urbanization, development, and climate change (Oteng-Ababio, 2014). Currently, over half of the global population and a significant portion of the human livelihood activities that impact global climate change are concentrated in cities (Rayner and Malone, 1997; Kates et al., 1998; O'Meara, 1999). Estimated urban population in 2050 – 6 billion – will be equal to the world's entire population in 2000 (UN-Habitat, 2014). This provides considerable opportunities for city authorities to shape appropriate policies over land-use planning and play a more important role in transportation issues and energy consumption, all of which have implications for greenhouse gas (GHG) emissions (Collier, 1997; Rayner and Malone, 1997; Agyeman et al., 1998; DeAngelo and Harvey, 1998; Kates et al., 1998; Bulkeley, 2000). The authority's ability to improve MSW management also provides opportunities to mitigate climate change and generate co-benefits such as improved public health and local environmental conservation.

Globally, rates of waste generation have been increasing. It is forecasted that the volume of MSW will double from the current waste generation rate of 1.3 billion tons per year in 2012 to 2.2 billion tons per year by 2025 (World Bank, 2012). The highest rate of waste generation is projected for the Asia-Pacific region, particularly in China, as shown in Figure 15.1, which presents the projected MSW generation globally in 2012 and 2025. These growing waste generation rates in developing countries experiencing increasing affluence have been phenomenal (UN-Habitat, 2011). Even though waste generation increases with affluence and urbanization (Barker et al., 2007), GHG emissions from MSW are lower in more affluent cities. In European and North American cities, GHG emissions from the waste sector account for 2.29–4.32% of the total urban GHG emissions. These shares are smaller than those of cities in Africa and South America, which have a higher share of GHG emissions from the waste sector, about 4.48–9.36% of their total urban GHG emissions (Marcotullio et al., 2014). This is because more affluent cities tend to have the appropriate infrastructure to reduce methane (CH_4) emissions from MSW that contribute to global anthropogenic GHG emissions (UNFCCC, 2005). Driven by urban population growth, increasing waste generation rates will severely strain existing MSW infrastructure in the urban areas of low- and middle-income countries.

While urbanization is a challenge, it creates a high concentration of people and services, which provides an opportunity to deliver efficient MSW services. In most developing countries, the challenge relates more to effective waste collection and better waste treatment systems to reduce GHG emissions from the waste sector. In contrast, developed countries have to contend with improved waste recovery through reuse and recycling as well as upstream

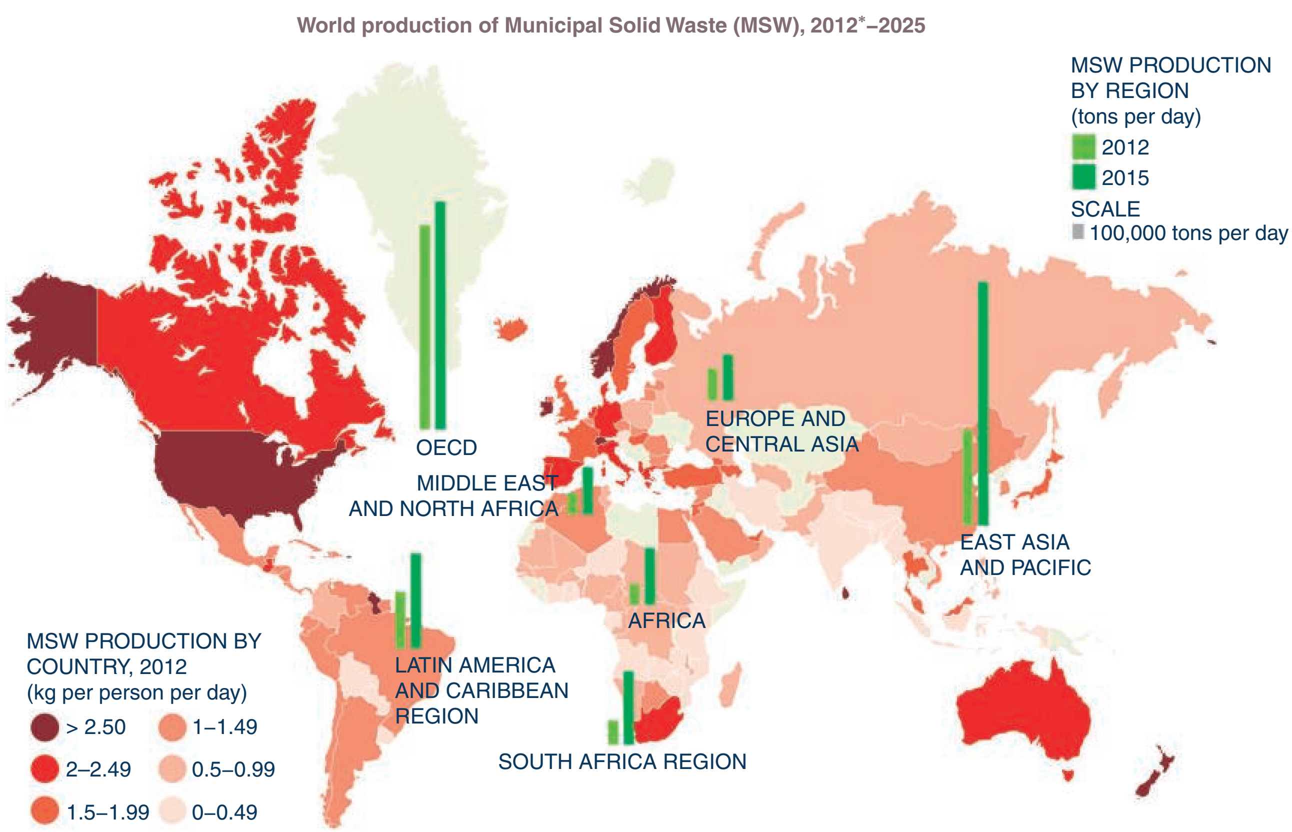

Figure 15.1 *World production of municipal solid waste (MSW), 2012–2025.*

Source: World Bank, 2012

interventions to prevent waste at source. MSW technologies alone are not sufficient to handle ever-growing waste problems. Stakeholder involvement, economic interventions, and institutional capacity are all important for enhancing the management of MSW. Therefore, multiple efforts involving with technical, environmental, social, and economic aspects must be considered when dealing with the complex task of MSW, thus indicating the need for an integrated approach to MSW management (Marshall and Farahbakhsh, 2013).

This chapter examines the concept of integrated solid waste management (ISWM). It demonstrates the current practices found in both developed and developing countries and highlights the challenges in achieving effective MSW management. The chapter examines ways through which proper, well-planned, and efficient SWM systems can mitigate climate change. The Case Studies suggest a number of ways in which city governments can address GHG emissions and also highlights several obstacles for local decision-makers. It also emphasizes the impacts of MSW on climate change emissions and climate change impacts related to discarded materials. Section 15.2 provides the background of the ISWM concept by focusing the definition of MSW and the development from the waste hierarchy concept to ISWM. Section 15.3 presents an overview of current MSW practices in developed and developing countries and their challenges in delivering better MSW management. Section 15.4 describes GHG emissions from MSW management practices, followed by the impacts of MSW on climate change in Section 15.5. Last, Section 15.6 focuses on the carbon market as a financial opportunity for GHG mitigation from waste.

15.2 Sustainable Solid Waste Management

15.2.1 MSW: Definition, Quantity, and Composition

The definition of MSW can be highly varied among countries. Usually, MSW refers to solid waste generated from community activities (e.g., residential, commercial, and business establishments). While construction waste and hazardous wastes are excluded as MSW in European countries, they are considered as MSW in most developing countries (Karak et al., 2012). Box 15.1 shows the comprehensive list of sources of MSW throughout the world.

Despite the inclusion of construction and hazardous wastes in MSW in some developing countries, the amount of MSW generated from developing countries is 648 million tons per year (World Bank, 2012). Notably, this amount generated by more than 170 countries is nearly as same as waste generation in developed countries comprising only 20 countries. The average values of waste generation per capita of developing countries are therefore relatively low, with a range of 0.45–1.1 kilograms per day, in comparison to those countries in the Organization for Economic Cooperation and Development (OECD) with an average value of 2.2 kilogram per person per day (World Bank, 2012).

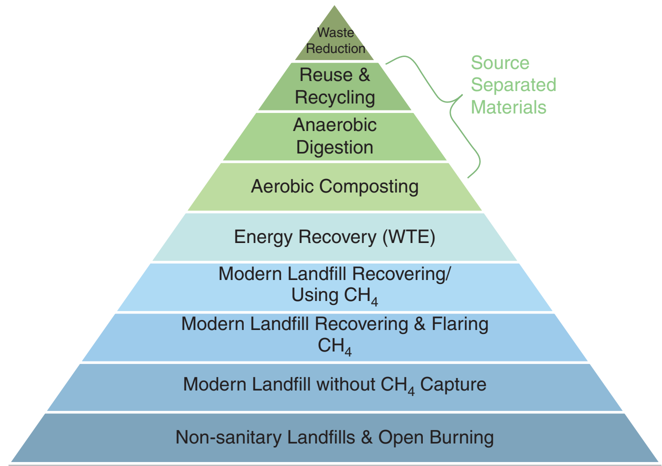

Figure 15.2 *The hierarchy of sustainable solid waste management.*

Source: Kaufman and Themelis, 2010

Common types of MSW are biodegradable material (e.g., food, garden waste), recyclable waste (e.g., paper, glass, metal, plastics), and other (e.g., textiles, leather). Based on the World Bank's data (2012), most low- and upper-income countries have a higher proportion of biodegradable waste, accounting for about 40–80% of the total volume of MSW. On the other hand, high-income countries have different waste composition. They have a higher share of paper and glass with a much lower portion of biodegradable waste, which represents about 30–40%.

15.2.2 Solid Waste Management Hierarchy

An important roadmap to ensure sustainable SWM is to address the concept of the sustainable SWM hierarchy, which is well recognized throughout the world (Kaufman and Themelis, 2010) (see Figure 15.2). Technically, all waste management strategies must aim primarily to prevent the generation of waste and to reduce its harmfulness. Where this is not possible, waste materials should be reused, recycled or recovered, or used as a source of energy. As a final resort, waste should be disposed of safely (e.g., in sanitary landfills or monitored dumpsites).

Box 15.1 The Definition of Municipal Solid Waste

Municipal solid waste (MSW), which is commonly called garbage, trash, or refuse refers to waste generated from the following activities:

- Residential (single and multifamily dwellings)
- Commercial (offices, stores, hotels, restaurants)
- Institutional (schools, prisons, hospitals, airports)
- Industrial (manufacturing, fabrication, etc., when the municipality is responsible for their collection)
- Nonrecycled construction and demolition debris
- Municipal services (street cleaning, landscaping)

As a concept, the historical antecedent of the waste hierarchy is traceable to the 1970s, when some environmental movements raised concerns about the then wholesale waste disposal-based approaches (Gertsakis and Lewis, 2003). The hierarchy is based on the "4Rs": reduce, reuse, recycle, and resource recovery (see Box 15.2), which collectively ensure waste reduction. As far as possible, disposal of materials in landfills should be considered only if none of the 4Rs is applicable and is therefore ranked lowest in priority.

15.2.3 Integrated Solid Waste Management (ISWM)

The concept of ISWM has been developed as a comprehensive approach that considers multidimensional aspects of SWM management in the integrated manner (McDougall et al., 2001). Both technical and nontechnical aspects of SWM must be incorporated because they are interdependent (UNEP, 2005). The aim of ISWM is to achieve a sustainable solution balancing environmental effectiveness, social acceptability, and economic affordability (McDougall et al., 2001; van de Klundert and Angchutz, 2001). As shown in Figure 15.3, ISWM requires stakeholder involvement and the consideration of six main aspects – environmental, political/legal, institutional, sociocultural, financial, and technical – for making decisions on waste systems that consist of the methods that will be used to sort, collect, transport, treat and dispose, reduce, reuse, recycle, and recover from waste. Unlike the priority order of the waste hierarchy, ISWM proposes a flexible framework for waste treatment systems. Rather than prioritizing reduction, recycling, and reuse of waste over treatment or

Box 15.2 Defining the 4Rs with the Waste Hierarchy

Reduce: This refers to waste avoidance and materials management (i.e., avoiding or reducing primary/virgin materials for manufacturing and preserving natural resources). This requires reducing financial and environmental resources in the collection, transport, treatment, and disposal of waste. For example, wastage can be minimized through reduced packaging, improved design, and use of durable materials.

Reuse: This refers to the practice of using materials over and over again for the same purpose for which they were intended. Reusing waste may require collection but relatively little or no processing.

Recycle: This refers to any activity that involves the collection, sorting, and processing of used or unused items that would otherwise be considered as waste into raw material that is then remanufactured into new products.

Resource recovery: This encompasses recycling, reprocessing, and energy recovery consistent with the most efficient use of the waste material. Resource recovery includes converting organic matter into useable products (such as compost and digestate) or energy recovery in the form of electricity and/or heat.

Disposal: If none of the above options is possible, then waste should be disposed of in a controlled manner. This includes using a sanitary landfill or pretreating the waste in other ways to prevent harmful impacts on public health or the environment.

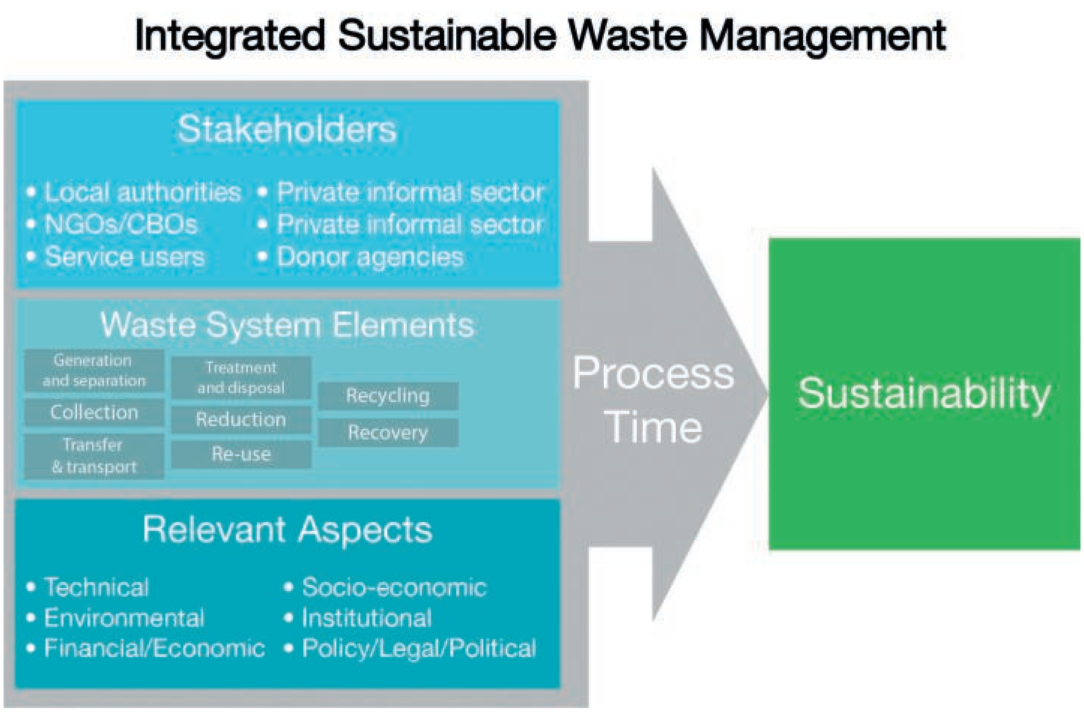

Figure 15.3 *Integrated solid waste management (ISWM) framework.*

Source: van de klundert and Angchutz, 2001 disposal, ISWM focuses on the use of a range of different methods to optimize resource conservation and limit final disposal (UNEP, 2005; Nordone et al., 1999). The combination of appropriate treatment methods, such as recycling, incineration, and landfilling, is necessary for MSW management because no single solution is sufficient for MSW disposal problems (Hoornweg and Bhada-Tata, 2012, in Menikpura et al., 2013).

15.3 MSW Management Practices Worldwide

MSW practices can be divided into four main activities:

- *Sorting and collection*: Waste sorting is the process of separating MSW into different types. Waste sorting can occur before or after the waste is collected. The collection process involves collecting waste from households, from community and street bins, or from bulk generators into larger containers or vehicles. It extends to activities such as driving between stops, idling, loading, and on-vehicle compaction of waste.
- *Recycling*: After waste sorting, recyclables are reprocessed into products.
- *Transfer and transportation*: This process involves the delivery of collected waste to transfer stations or treatment facilities.
- *Treatment and disposal*: Waste treatment is the process of disposing of waste after collection. Waste can be buried at landfills or burned through the incineration process. Non-recyclable waste items can be converted into compost or energy as various forms of useable heat, electricity, or fuel.

These four activities are used to analyze the current MSW practices as described next.

15.3.1 MSW Management Practices in Developed Countries

As recently as the 1970s, the practices in most developed countries were similar to the present situation in most transitional/developing countries with low waste collection rates and improper disposal of waste. The stimulus for change was damage to public health due to improper practices inside cities, at disposal sites, or in surface water or groundwater, which attracted several political and media commentaries (UN-Habitat, 2010). At this point, it became necessary to phase out open dumps and develop and operate state-of-the-art sanitary landfills. Another strong influence was public opposition (not-in-my-backyard or NIMBY) to new waste management projects, based at least in part on bad experiences with previously uncontrolled sites. Over the past few decades, high-income countries gradually overcame NIMBY by making project planning and implementation transparent, engaging communities, and implementing safe management practices.

15.3.1.1 Waste Sorting and Collection

In developed countries, the public is often trained to segregate their waste. Households usually carry out waste sorting at the source. Collected waste is segregated further at material sorting facilities, and the materials are recovered through recycling. For source sorting, waste is put into different containers, such as bags, bins, or rack sacks. The number of waste streams separated varies depending on the waste collection policy of each municipality. Usually, glass and paper are sorted at the source, and biodegradable waste is sorted and collected separately in most municipalities (Xevgenos et al., 2015).

Developed countries have developed technologically advanced SWM systems with waste collection coverage of greater than 90%. Collection systems that have a high degree of mechanical handling of the waste are usually employed in high-income countries; these include:

- *Full-service schemes* (door-to-door) and curbside collection services in neighborhoods where collection trucks provide door-to-door or curbside services
- *Drop-off systems* (or communal container collection); this system requires individual households to bring their waste to containers placed for each community or to drop-off centers
- *Private cars delivering waste to collection points* or driving a personal car with a load of waste to a facility and back to the house
- *Pneumatic pipe systems* used by multifamily neighborhoods; these can transport waste from a building's garbage chute using a vacuum created by electric fans and vents to a central collection point. Waste from the central collection points is then collected by trucks (Rypdal and Winiwarter, 2001; Monni et al., 2006).

Dual collection and highly mechanized vehicles like compactor trucks are commonly used for collecting waste. The former is efficient for collecting recyclables and the latter has the capacity to carry a large amount of dry waste (UNEP, 2005).

In addition, railways and barges are some of the most commonly used modes of waste transportation, although communities that want to use barges or railways should have access to existing port and rail infrastructure, respectively (Mogensen and Holbech, 2007; Saxena, 2009).

15.3.1.2 Recycling

Recyclable waste items, which are sorted at the source or at recycling centers, are reprocessed into products. There are three types of reprocessing operation: upcycling, recycling, and downcycling. *Upcycling* is the reprocessing of waste materials into products that have higher value than the original. *Recycling* processes produce products that have the same value with the original or can be used for the same purpose, whereas *downcycling* converts waste materials into products that have less value than the original and serve for lower application. On average, 22% of the total MSW was recycled in high-income countries (World Bank, 2012), and an ambitious target of 50% of municipal waste to be recycled by 2020 is set for European countries (European Union [EU], 2010).

15.3.1.3 Waste Transfer and Transport

Collected waste is delivered to transfer stations, recycling centers, treatment facilities, or disposal sites through optimized routes.

15.3.1.4 Treatment and Disposal

Two technologies are widely applied in developed countries for MSW treatment:

- *Thermal technologies* refer to technologies that operate at high temperatures to produce heat or electricity as a primary byproduct. Thermal technologies, such as gasification and pyrolysis, are the advanced form of incineration and are suitable for processing dry waste with low moisture content.
- *Biological technologies* require lower temperatures than thermal technologies for the operation. Examples of these technologies are anaerobic digestion, composting, biodiesel, and catalytic cracking. They are considered appropriate treatment systems for biodegradable waste. Byproducts of these technologies include electricity, biogas, compost, and chemicals.

Approximately, 21% and 11% of MSW was incinerated and composted in high-income countries (World Bank, 2012), respectively. Apart from energy and other byproducts, solid residuals are created during waste treatment operations. These solid residuals, which represent about 42.5% of MSW, are then disposed of at sanitary landfills using a system to capture landfill gases for energy recovery or flaring.

A critical component that keeps such highly advanced SWM systems running in developed countries is the government's ability to implement existing policies and regulations, which requires significant human and financial resources (World Bank, 2012). Table 15.1 presents a summary of instruments adopted in developed countries to promote sustainable waste management and efficient resource use.

15.3.2 MSW Practices in Developing Countries

15.3.2.1 Waste Sorting and Collection

Unlike high-income countries where there is public awareness of waste sorting, sorting activities at the household level in low- and middle-income countries are still limited. Therefore, the MSW generally consists of mixed waste containing food and other types of waste. Waste sorting is usually conducted by poor families to earn extra income from selling recyclable materials. Despite the high amount of municipal budget spent for waste collection, about 80–90% of the total MSW budget, the efficiency of MSW collection is still very low in many countries, particularly those in Sub-Saharan Africa, which has collection rates ranging from 17.7% to 55% (World Bank, 2012). Due to low waste collection efficiency, dumping waste on the roadside is a common practice (APO, 2007). Although the use of covered and compactor trucks for collecting waste is increasing, transporting MSW by inefficient and open vehicles is a common practice in urban areas (APO, 2007).

15.3.2.2 Recycling

In contrast to high-income countries where recyclables are collected through curbside or drop-off systems, informal sectors, like the waste pickers sector, play a significant but largely unrecognized role in handling such activities (Troschinetz and Mihelcic, 2009). Waste pickers collect recyclable waste materials from collection and disposal points, and mobile purchasers carry out house-to-house services (APO, 2007). Informal recycling contribution varies in different cities. It is estimated that the recycling rate of MSW collected by waste pickers is in the range of 3–8% of waste transported to disposal sites in Indonesia (Sasaki and Araki, 2014) and 15% and 20% of the waste generated in India and Vietnam, respectively (Chintan, 2009; APO, 2007). Figure 15.4 shows several waste pickers in Accra, Ghana, sorting and baling recyclable materials prior to taking them to their respective recycling companies. Baling reduces the volume of waste to be collected and optimizes transport. The participating shops save significantly on their monthly waste collection bills.

15.3.2.3 Waste Transfer and Transport

In developing cities, street networks characterized by improper planning, small size, and poor condition are a major barrier to enhancing the efficiency of waste collection.

15.3.2.4 Waste Treatment and Disposal

Open dumping and landfilling (see Figure 15.5) are the most common methods of MSW disposal in developing countries, mainly because they are cheap when social and environmental impacts are not considered (Renou et al., 2008; Ali et al., 2014). Together, these two methods account for about 70–90% of the total MSW (World Bank, 2012). Compared to other treatment methods, open dumping and landfilling pose the highest risk to environmental and human health, causing deterioration of soil and water quality, air pollution, and the spread of disease by insects and rodents. The use of incineration is still very limited due to high investment cost and inappropriate waste composition dominated by inerts and biodegradable waste. Composting has long been promoted as a mean of treating biodegradable waste and generating extra income for communities; however, several problems arise for composting practices at household and municipal levels. Most households lack motivation for separating their food waste, and composting plants operated by municipalities often face technical problems due to lack of expertise and the use of mixed MSW, which produces poor-quality compost (Furedy, 2004). The application of composting practices is therefore still limited to small-scale or pilot projects.

The overview of MSW management practices in both developed and developing countries is given in Table 15.2. It clearly shows several problems in the handling, collection, transfer and transport, treatment, and disposal of solid waste in developing countries. This implies an urgent need to shift from poor management of MSW to a more effective MSW management system

Table 15.1 *Economic and regulatory instruments employed in developed countries to achieve sustainable management of MSW.* Source: Xevgenos et al., 2015

TYPE OF INSTRUMENT	OBJECTIVE	REQUIREMENT	ISSUES
		Economic instruments	
Extended Producer Responsibility (EPR)	To extend the responsibility of post-consumer waste to the manufacturers of the goods by requiring them to redesign products using fewer materials and with increased recycling potential. Different waste streams are included in EPR schemes such as packaging waste, batteries, end-of-life-vehicles (ELVs), oils, waste electronic and electronic devices (WEEEs).	The operational responsibilities for a producer responsibility scheme are: 1. Physical responsibility for collecting the products 2. Financial responsibility for paying fees to support collecting and recycling activities. The fees are country-specific and can be weight-based or/and material-specific.	Requirement for clear distinctions in the allocation of the operational responsibilities between the local authorities and the industry in collecting wastes.
Deposit-Refund	To increase and capturing the used packaging (i.e., mainly beverage bottles/cans) for recycling.	Customers are required to pay for a deposit on top of the product's price, when they buy a product. This deposit will be reimbursed to them partially or fully when the product is returned to a trader or a specialized treatment facility.	Decrease in the use of reusable packaging leads to the higher prices of products contained in reusable containers and the preference of users for separate collection in view of convenience.
Landfill/Incineration Tax	To internalize external costs of landfilling, to provide incentives for diverting waste from landfills.	A charge levied by a public authority to the individual households on the disposal of waste and is usually calculated based on the amount of waste disposed (weight-based).	Lack of a direct incentive to citizens for reducing their waste because the tax is not based on the amount of waste generated by each household. Consideration of optimized charges as low charges may not provide sufficient incentive against landfilling while high charges may lead to illegal disposal.
Pay-As-You-Throw (PAYT)	To internalize external costs of MSW disposal based on the amount of waste disposed by each household. This is aimed to create an incentive for households to recycle more and to generate less waste.	Residents are charged for the collection of municipal solid waste – ordinary household trash – based on the amount of waste they generate.	High charge rate can lead to illegal waste dumping. Suitable rate for different waste stream. It is suggested that a PAYT scheme should charge: a) The highest fee for residual waste b) A lower fee for biowaste c) Zero fee for kitchen waste d) A low or zero fee for dry recyclables
		Regulatory Instruments	
Bans and Restrictions (e.g., a landfill ban)	To reduce dependency on landfills and to shift waste management up the waste hierarchy.	A variety of bans and restrictions are found in different countries such as. Landfill bans on unsorted/untreated waste or residual waste. Restriction on separated waste collection. A ban on the use of plastic bags in restaurants, large supermarkets, and all retail stores.	Bans and restrictions on residual waste have low potential for material recovery and usually result in increased incineration rates. Although bans and restrictions are powerful means, they do not create revenues.
Mandatory Source Separation	To increase recycling rate and enhance the efficiency of MSW management.	The municipalities or households must comply with the requirement to separate waste before disposal. Those who do not comply with the requirement have to pay a fine.	Requires a consideration of the number of waste streams needed to be separated.

Case Study 15.1 The Solid Waste Management Challenge of a Rapidly Developing Economy City: The Case of Rio de Janeiro

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Keywords	Municipal waste management, poor source separation, formalized informal sector
Population (Metropolitan Region)	11,835,708 (IBGE, 2015)
Area (Metropolitan Region)	5,328.8 km^2 (IBGE, 2015)
Income per capita	US$8,840 (World Bank, 2017)
Climate zone	Am –Tropical monsoon (Peel et al., 2007)

Case Study 15.1 Figure 1 *Rio de Janeiro landfill.*

Like many municipalities in Brazil, waste collection and disposal services in Rio de Janeiro are coordinated by the municipality of Rio (COMLURB), and collection fees are incorporated into Rio's property taxes (Monteiro, 2013; IBGE, 2015). Generally, collection systems in low-income communities are inadequate, mainly because these areas are not easily accessed with traditional collection vehicles. COMLURB employs approximately 20,100 employees and has a reported annual budget of US$500 million (IBGE, 2015). Municipal authorities often spend between 20% and 30% of their budgets on cleaning and waste disposal, with around 70% related to transportation costs (Brookings Institution, 2015).

Rio de Janeiro citizens produce approximately 4,500 tons of MSW per day (IBGE, 2015), exhibiting lower calorific value (~8 MJ/kg), compared to the EU average (~10 MJ/kg) and the U.S. average (~11 MJ/kg). Reported recycling rates are at about 98%. However, recycling is mainly supported by the informal sector, where waste pickers manually sort materials to be recovered from waste bins and recycling facilities (IBGE, 2015). However, the public perception of scavengers is often negative, leading to the social isolation of these groups, and the importance of these groups for a sustainable waste management is not recognized. In addition, these groups are normally collecting recyclable waste without protective equipment, thus creating a significant problem for public health (World Bank, 2013).

Four transfer stations and two material recovery facilities are operating in Rio, employing approximately 160 people from the low-income communities (World Bank, 2013).

Rio recently closed its primary disposal site (i.e., the public Gramacho landfill) and began sending the bulk of its waste to a new sanitary landfill (Seropedica) located nearly 70 kilometers outside the city. The new sanitary landfill, which has an expected lifetime of 30 years, is operated and owned by a private consortium. However, the Seropedica landfill in Rio de Janeiro is being built over an underground water reservoir and concerns about public health are emerging. At the Gramacho landfill, a new biogas purification plant will deliver 10,000 cubic meters of high-grade gas per day to one of the country's main refinery complexes through a 5,500 meter pipeline (WorldinTwelve, 2015).

Approximately 50% of household waste is organic material. The city currently operates a 200 ton-per-day composting plant that uses feedstock mainly from wholesale food markets and organic waste that has been separated at the material recovery facilities. The municipality of Rio diverts other waste streams, such as tree prunings from city parks and streets, to compost.

The new Brazilian policy on Solid Waste Management (PNRS), law 12.305 took effect on August 2, 2010, after 20 years of discussions in Congress. PNRS is a promising step forward; however, it is linked to many different lobbies and has resulted in a misleading legislation document. The main bottlenecks can be summarized as follows:

- It does not adopt or propose the waste management hierarchy to be followed by the involved parties.
- It defines landfilling as an "environmentally acceptable" solution, juxtaposing the widely accepted waste management hierarchy.
- It contains only fifteen objectives; therefore, a more comprehensive approach is needed. The involved bodies should take into consideration the Waste Directives implemented by the European Commission, such as the Waste Framework Directive and the zero waste approach toward a circular economy.

Rio participates in the Climate and Clean Air Coalition (CCAC), which is a voluntary partnership uniting governments, intergovernmental and nongovernmental organizations, and representatives of civil society and the private sector in a global effort to address ways of mitigating emissions of short-lived climate pollutants, including methane and black carbon, as a collective challenge. The CCAC Municipal Solid Waste Initiative is working with government officials, sanitation engineers, private entrepreneurs, and other stakeholders in Rio to help build capacity to improve waste management.

Policies, financing, and creative programs are providing the backdrop for urban revitalization and sustainable growth in Rio de Janeiro. For example, the Morar Carioca program is improving housing and services in informal settlements, while BikeRio is creating a cycling culture around cleaner and more accessible transport, and Bolsa Verde do Rio de Janeiro lays the groundwork for innovative emissions, effluent, and ecosystem services markets. Across this city, agencies from all levels of government, nongovernmental organizations, academia, and the private sector are working together to approach long-standing and emerging challenges with fresh ideas and clear commitment; however, lots of effort is still required (WorldinTwelve, 2015).

Case Study 15.2 The Challenge of Developing Cities: The Case of Addis Ababa

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Keywords	Municipal waste management, no-source separation, open dumping, informal recycling systems
Population (Metropolitan Region)	32,220,000 (Government of Ethiopia, 2012)
Area (Metropolitan Region)	540 km^2 (Government of Ethiopia, 2012)
Income per capita	US$590 (World Bank, 2017)
Climate zone	Cfb – Temperate, without dry season, warm summer (Peel et al., 2007)

In Addis Ababa, on average, 0.4 kilograms per capita per day of municipal solid waste (MSW) is produced, whereas more than 200,000 tons was collected in 2013 (Future Mega Cities, 2015). The city's MSW composition exhibited high organic content (~60% of total MSW), and the recyclables fraction was about 15% in 2013. The high amounts of organic waste as well as paper and cardboard that go for disposal can result in large amounts of greenhouse gases (GHG) being emitted, and here the largest reduction potential can be found. The city is divided into 549 zones, representing 800–1,000 households. In each zone, one micro- and small-scale enterprise is responsible for the collection of MSW, employing 5,815 operators (Government of Ethiopia, 2012). The financing for solid waste management is volume-based at a rate of 30 birr per cubic meter (approx. US$1.50). Services charges are fixed with respect to water consumption, taking into account the ability and willingness of the residents to pay. MSW collection is regular and covers 80% of the city's needs. Sorting of waste takes place at various levels in the waste management process. The municipality increased the collection rate from 60% to 80%, and the sources of waste generated can be summarized as follows:

- 76% households
- 18% institutions, commercial, factories, hotels
- 6% street sweepings

The first level of source separation is at the household level, where plastic, glass, and bottles are considered as valuable materials and typically sorted out for reuse. There are independent collectors supporting the informal sector and active at the second stage of source separation, such as street boys, private-sector enterprises, and scavengers at municipal landfill and the korales, collecting metal, wood, tires, electronic products and appliances, old shoes, and plastic, which are further used by local plastic companies, shoe manufacturers, and metal factories. The municipality's role in recycling is absent and mainly focuses on collection, storage, transportation, and disposal of solid waste.

The highest level in the transportation system is represented by the municipality. The role of the private sector in transportation of solid waste is limited. There is currently one open dumpsite with a surface area of 0.25 square kilometers (0.1 square mile) ("Rappi" or "Koshe") where all collected waste is disposed of; it is located 13 kilometers southwest of the city center; it opened almost 50 years ago (Regassa, 2011). The major problems associated with the disposal site are that it is reaching its capacity and is surrounded by housing areas and institutions, creating a nuisance and health hazard for people living nearby. There is no daily cover with soil, leachate containment or treatment, rainwater drain-off, or odor or vector control. The present method of disposal is open dumping: hauling the wastes by truck, spreading and leveling by bulldozer, and compacting by compactor or bulldozer. Environmental sanitation activities and campaigns should start operating in Addis Ababa, and the installation of bins and the development of effective collection systems, transfer stations, and new sanitary landfills are important. An emphasis on recycling and reusing should be implemented.

The collection of information regarding the actors involved in the waste management system and how the material and resource flow through a megacity is a great challenge in any large urban center in a developing country because of the complexity of the system.

In Addis Ababa, there is neither legislation advocating sustainable waste management nor a plan for integrated waste management. There is a need to incorporate the informal recycling sector within the formal sector and, through educational programs, to advance the role of waste pickers and scavengers in the society. In addition, the municipality of Addis Ababa should create robust secondary markets to aid waste pickers in their role of advancing waste management in the city. This could be a great step forward; however, a lot still needs to be done by the citizens and Addis Ababa authorities to achieve sustainable waste management; an achievement that cannot be done overnight.

It is in this light that the attempt by the Addis Ababa City Administration, UNDP MDG Carbon, and UNDP Ethiopia Country Office to work together to support the development of the Repi Landfill Gas Clean Development Mechanism (CDM) Project under the UN Framework Convention on Climate Change (UNFCCC) was commendable (see UNDP, n.d.). Conceptually, the CDM project is based on the capture and destruction of the harmful greenhouse gas (GHG) methane produced by decomposing organic matter at the landfill site. The action of capturing and flaring methane has been made possible through revenue from the sale of certified emissions reductions (CERs). When successfully implemented and operated, the project was to generate

Case Study 15.2 Figure 1 *Addis Ababa landfill.*

a combination of economic, social, and environmental benefits. First, carbon credits were to help to make economically viable a project that would not otherwise happen by bringing additional revenues to the City of Addis Ababa. Second, social benefits would arise from green jobs, which would have been created for scavengers who currently live on the landfill. Third, the project would have delivered important environmental benefits through reducing GHGs that would otherwise be emitted into the atmosphere and contribute to global warming.

The project failed, however, due to financial and other administrative challenges (Bond et al., 2012). Furthermore, the difficulty of the task was compounded by a lack of a robust database (e.g., quantities and composition of waste generated) and by the fact that a large part of the waste and resources is managed and recovered informally or at the interface between the informal and formal sectors. This requires multiple perspectives to understand the problems associated with waste management in a megacity and a transdisciplinary approach for the collection of data and information.

using innovative and integrated approaches. The major challenge is the lack of adequate administrative and financial resources to support such transformation, the absence of effective and comprehensive legislative frameworks, inadequate enforcement mechanisms, the use of improper treatment technologies, and the lack of stakeholder involvement (Guerrero et al., 2013). Consequently, great efforts should be made to develop suitable financing mechanisms for enabling effective MSW management, the intervention of proper treatment technologies for the waste characteristics and local contexts of developing countries, the development of proper standards and laws enforcing waste separation/minimization, capacity-building of the local authorities in MSW management, and cooperation between citizens and local authorities in the planning and implementation of management activities to achieve appropriate and effective waste management practices.

15.4 GHG Mitigation Potential of Sustainable Waste Management

MSW management activities like collection, transportation, treatment, and disposal generate GHG emissions. The majority of GHGs are emitted during the disposal phase in sanitary landfills and dumpsites. Comparatively, GHG emissions from other activities like collection, transportation, and treatment are low. In principle, all these activities entail the movement of waste from the generation point to other facilities, which involves the use of different sources of energy and fuels, thus potentially resulting in GHG emissions. Other sources of GHG emissions involve compaction of waste and maintenance of waste collection and transport equipment including bins, containers, and vehicles, as well as construction of infrastructure and facilities. The following subsections highlight some of these sources.

Globally, it is expected that waste generation per capita will increase by approximately 30% from current levels, while total MSW generation will increase almost threefold (Hoornweg et al., 2012). With increasing waste generation also comes an increasing amount of biodegradable organic waste, which in turn leads to increased GHG emissions due to anaerobic decomposition in landfills and dumpsites. Waste prevention seems to be a promising approach to minimize the amount of waste. Reducing waste through product design and reusing materials and through concepts like circular economy hold enormous potential for indirect reduction of GHG emissions through the conservation of raw materials, improved energy and resource efficiency, and fossil fuel avoidance (Saxena, 2009). With improved material management that uses a combination of reduced packaging, reduced use of non-packaging paper products (e.g., magazines, newspapers, and textbooks), and extended life of personal computers in U.S. industry, high amounts of GHG emissions reduction, up to 255 $MMTCO_2e$ per year can be achieved (Environmental Protection Agency [EPA], 2009).

Waste prevention and reduction can also mitigate GHG emissions through:

- Substituting virgin raw material and reducing GHG emissions from virgin raw material procurement and manufacturing (i.e., avoiding baseline emissions attributable to current production)
- Forest carbon sequestration, in the case of paper products (also treated as negative emissions)
- Zero waste management GHG emissions (EPA, 2009)

15.4.1 GHG Emissions, Waste Sorting, and Collection

Considering the high amount of mixed wastes disposed of in developing countries, high amounts of GHG emissions are generated from the degradation process of biodegradable waste. Source separation of organics from other waste streams therefore provides great potential for reducing GHG emissions from landfill sites. The study of MSW practices in China indicates the possibility to reduce about 23% of GHG emissions through source-separated collection compared with the existing practice using a mixed waste collection system (Dong et al., 2013).

Collection systems involve both mechanical and manual handling of waste. While collection systems with a higher degree of manual handling reduce GHG emissions, they might have other drawbacks that also need to be considered. In estimating the GHG emissions associated with waste collection, only the energy used when operating the collection trucks is considered. Table 15.3 presents diesel consumption per ton of waste collected from different waste generation sources.

(a) (b)

Figure 15.4a and 15.4b *A typical dumping site in Accra, Ghana.*

Photos: Ranjith Annepu, www.wastewise.be

Box 15.3 Informal Recyclers in Accra

Informal waste pickers handle large quantities of waste that would otherwise have to be collected and disposed of by Accra's authorities. By doing so, the informal recycling sector saves the city 20% or more of its municipal solid waste (MSW) budget, which by implication means that the poor are subsidizing the rest of the city. The city has a major opportunity to build on the existing recycling systems to increase its existing recycling rates further and to protect and develop people's livelihoods while reducing the costs of managing residual wastes.

Box 15.3 Figure 1 *E-waste scavengers in Accra burning wires to harvest copper.*

15.4.2 GHG Emissions and Transportation of Waste

GHG emissions from the transportation of waste also depend on the density of the material transported and the degree of compaction it was subjected to. Modern materials like plastic, paper, and cardboard have low density but are more compactable than are metals or organic and inorganic materials that have a higher density. Studies (Spielmann et al., 2004; Securities and Exchange Commission [SEC], 2006; Environmental Design of Industrial Products [EDIP], 2004) show that fuel consumption is higher for materials with low density when assessed per ton of material transported.

Table 15.2 *Municipal solid waste management practices worldwide. Source: The World Bank, 2012*

Activity	Developing country	Developed country	
	Low-income country	**Middle-income country**	**High-income country**
Source reduction	Not organized, but reuse and low per capita waste generation rates are common.	Some discussion of source reduction, but rarely incorporated into any organized program.	Organized educational programs are beginning to emphasize source reduction and reuse of materials.
Collection	Sporadic and inefficient. Service is limited to high-visibility areas, the wealthy, and businesses willing to pay.	Improved service and increased collection from residential areas. Larger vehicle fleet and more mechanization.	Collection rate >90 percent. Compactor trucks and highly mechanized vehicles are common.
Recycling	Most recycling is through the informal sector and waste picking.	Informal sector still involved; some high technology sorting and processing facilities. Materials are often imported for recycling.	Recyclable material collection services and high-technology sorting and processing facilities. Increasing attention toward long-term markets.
Composting	Rarely undertaken formally even though the waste stream has a high percentage of organic material.	Large composting plants are generally unsuccessful; some small-scale composting projects are more sustainable.	Becoming more popular at both backyard and large-scale facilities. Waste stream has a smaller portion of compostable than in low- and middle-income countries.
Incineration	Not common or successful because of high capital and operation costs, high moisture content in the waste, and high percentage of inert material.	Some incinerators are used, but experiencing financial and operational difficulties; not as common as in high-income countries.	Prevalent in areas with high land costs. Most incinerators have some form of environmental controls and some type of energy recovery system.
Landfilling	Low-technology sites, usually characterized by open dumping of wastes.	Some controlled and sanitary landfills with some environmental controls. Open dumping is still common.	Sanitary landfills with a combination of liners, leak detection, leachate collection, and treatment systems.
Costs	Collection costs represent 80–90% of the municipal solid waste management budget. Waste fees are regulated by some local governments, but the fee collection system is very inefficient.	Collection costs represent 50–80% of the municipal solid waste management budget. Waste fees are regulated by some local and national governments, more innovation in fee collection.	Collection costs can represent <10% of the budget. Large budget allocations to intermediate waste treatment facilities. Upfront community participation reduces costs and increases options available to waste planners (e.g., recycling and composting).

More obvious factors that influence GHG emissions from transportation are the distance between the waste generation source and final disposal site and the size of the waste container. The bigger the size of the container, the less the GHG emissions rate per tons of waste transported per kilometer. An extreme case of GHG emissions from waste transportation is small cars and motor carts transporting small amounts of waste over the road, but such modes are used around the world where collection and transportation services are inadequate or expensive (Larsen et al., 2009).

All MSW management activities consume energy, either through the use of electricity[1] (e.g., to power pneumatic collection systems, balers, trains), diesel fuel (e.g., for trucks, trains), petrol (e.g., for private vehicles), bunker oil (e.g., barges, coasters, container ships), or natural gas (e.g., for fork-lifts and trucks) (Gertsakis and Lewis, 2003). Fruergaard et al. (2009) summarized the volume of GHG emissions (expressed as kg/CO_2-eq) generated from different sources (see Tables 15.4 and 15.5).

15.4.3 GHG Emissions and Recycling

The GHG emission benefits from recycling are quite substantial as compared to other methods of waste management (see Table 15.6). Recycling can potentially reduce emissions because less waste is brought to the landfill and less virgin resources are extracted, hence the energy required for extraction and processing of primary resources is reduced. A comparative study of treatment practices in the Netherlands shows that high-quality recycling saves 2.3 MtCO_2 per year, which is higher than that achieved from improved efficiency incineration systems, which could reduce only 0.7 MtCO_2 per year (Corsten et al., 2013). Table 15.6 demonstrates the potential GHG emission reduction from recycling activities. In 2002, Canada recycled 4.3 million

1 Electricity is considered a mixed energy supply since in some countries nuclear, hydro, solar, and wind power may, together with fossil energy sources, contribute to the national grid mix

Table 15.3 *GHG emissions (kg $CO_{2\text{-eq}}$) from the use of fuel per ton of waste collected. Source: Larsen et al., 2009; StatBank Denmark, 2008; Mogensen and Holbech, 2007*

Collection	GHG emissions (kg $CO_{2\text{-eq.}}$/ton)
Full service/curbside collection:	
Residual waste, city center	9.3–9.9
Residual waste, apartment blocks	5.0–5.4
Residual waste, single-family houses	10.2–11.5
Residual waste, rural areas	19.5–32.3
Paper waste, apartment blocks	6.8–11.2
Paper waste, single-family houses	12.7–21.1
Drop-off containers:	
Glass waste, 0.7–2.5 m^3	11.5–15.7
Paper waste, 0.7–2.5 m^3	15.2–15.7
Private car:	
5–10 km one way carrying 15 kg	100–300
5–10 km one way carrying 100 kg	16–45
Pneumatic systems:	
Stationary systems	17.5–77.1
Mobile systems	43.0–45.6

Case Study 15.3 Integrated Community-Based Waste Management toward a Low-Carbon Eco-City in Tangerang Selatan, Indonesia

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Keywords	Integrated waste management, material recovery, voluntary emission reduction, community-based actions
Population (Metropolitan Region)	1,290,322 (Badan Pusat Statistik, 2017)
Area (Metropolitan Region)	147.19 km^2 (Badan Pusat Statistik, 2017)
Income per capita	US$11,220 (World Bank, 2017)
Climate zone	Af – Tropical, rainforest (Peel et al., 2007)

Five years after administratively separating from the Tangerang Regency, the city of Tangerang Selatan has shown very fast development. The city is located in Banten Province and is part of the Greater Jakarta Metropolitan area, and about 30% of the city's inhabitants work in Jakarta. The share of residential areas reached about 52% of the total city area in 2013 with 3–4% annual population growth (DTKBP, 2011, 2014).

Facing the challenges of limited land availability and growing gastronomic tourism forces the city to confront problems in the waste sector. The city urgently needs innovative strategies to cope with these challenges through integrated regions that can support sustainable development, especially in the waste sector, in order to move toward a low-carbon eco-city.
Tangerang Selatan's landfill, the Cipeucang Landfill, was re-established by the city's authorities in 2011. Currently, this 2.5 hectare landfill has reached more than 70% of its maximum capacity and another 1.5 hectares was developed in 2015 (DKPP, 2014). This critical condition forced the city to change its waste management strategy toward waste reduction at the source level, mainly through integrated community-based waste management.

THE WASTE SECTOR AND A LOW-CARBON ECO-CITY

Waste management in Tangerang Selatan follows a holistic approach. It applies at multiple levels from the source to the landfill, with the goal of minimizing waste at the landfill, maximizing the utilization of recyclables, and avoiding greenhouse gas (GHG) emissions from organic waste, in parallel with the government's *"Indonesia Bersih Sampah 2020"* or "Indonesia Clean Waste 2020" program.

The city generates 700–1000 tons of waste per day (DKPP, 2014), which contains 51% organics, 35% non-organics, and 15% residue (DKPP, 2014). About 114 tons of mixed waste is brought to the landfill per day. The rest is treated at Recycle-Banks (RB), Material Recovery Facilities (MRF), by the private sector and through illegal burning and dumping (DKPP, 2014).

The Department of Cleanliness, Parks and Cemeteries (DKPP) serves 41% of the residents (DKPP, 2014). At the source, the city authority relies on community-based waste management. The city plans to implement 54 MRFs (one per subdistrict) by 2016, along with 572 Recycle Banks (RB) (one per neighborhood association). By the end of 2016, the city expects to reduce by 20% incoming waste to the landfill through this integrated waste management program. Also, communities are expected to play active roles in utilizing the waste, following Reduce, Reuse, and Recycle (3R) principles such as organic and non-organic waste separation (see Case Study 15.3 Figure 1).

An RB or *Bank Sampah*, uses the concept of reutilizing recyclable waste for useful products (bags, pencil cases, book covers, etc.). Recycle Banks were introduced by the Indonesian Ministry of Environment. The operations of RBs are driven by housewives or community initiatives (see Case Study 15.3 Figure 2). Many RB activities are not limited to handicrafts but can also include agricultural activities, such as the planting of herbs and houseplants. Currently, the city has 145 RBs, which serve around 8,500 inhabitants and have handled around 700–900 tons of non-organic waste since they were first opened.

Case Study 15.3 Figure 1 *Waste separation by the community at the Material Recovery Facility.*

Source: BORDA, 2014

The concept of the Material Recovery Facilities (MRF) or *Tempat Pengelolaan Sampah* 3R was introduced by the nongovernmental organization (NGO) Bremen Overseas Research and Development Association (BORDA) and partners (Bina Ekonomi Sosial Terpadu, Lembaga Pengembangan Teknologi Pedesaan, and Bali Fokus) in 2004, and adopted by the Indonesian Ministry of Public Works in 2007. In Tangerang Selatan, implementation of MRFs started in 2010. The MRF concept emphasizes waste management at the local level through community-based organizations (CBO) to deal with organic and non-organic waste (see Case Study 15.3 Figure 3). Currently, 51 MRFs run in the city and serve around 125,000 inhabitants.

Within the last four years, the implementation of RBs and MRFs has encouraged about 10% of residents to be actively and voluntarily involved in waste reduction at the source level. This contributes to emission reductions from the waste sector in two ways: preventing emissions generation at the landfill and preventing emissions generation at source. This number is expected to increase in the coming years and contribute significantly to load reduction at the landfill and to reducing the burden of the Department of Cleanliness, Parks and Cemeteries.

FROM VISION TO MISSION: CLIMATE CHANGE MITIGATION

The city authority developed a study of climate change mitigation in Tangerang Selatan. This study reported potential GHG generation from different city sectors, including industries, transportation, energy, and waste. The results are used as guideline for further policies, strategies, and action plans in climate change mitigations.

The city has enforced previous acts for environmental protection, such as Local Regulation No. 13/2013 on Environmental Treatment that regulates the environment in Tangerang Selatan (Perda No. 13/2013 tentang Pengolahan Lingkungan Hidup yang Mengatur Pengelolaan Lingkungan, Badan Lingkungan Hidup Daerah; BLHD, 2013) and Local Regulation No. 3/2013 on solid waste management (PERDA No. 3/2013 tentang Pengelolaan Sampah, Dinas Kebersihan Pertamanan dan Pemakaman; DKPP, 2013). For the waste sector, the city authority obliges housing developers to connect to one of the MRFs in every new housing settlement.

Case Study 15.3 Figure 2 *Recycle Bank activities, which focus on recyclables.*

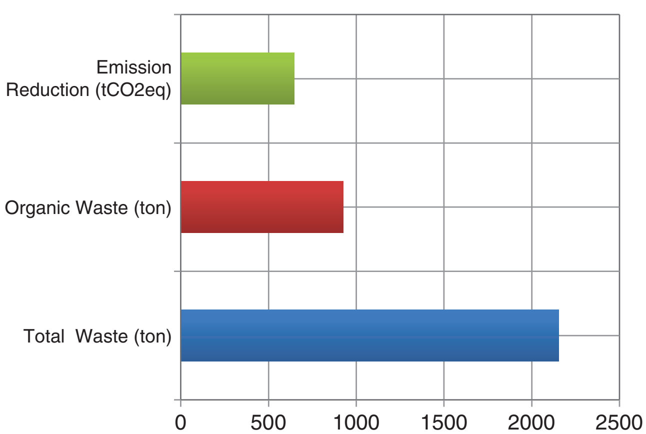
Source DKPP, 2014

Case Study 15.3 Figure 3 *Material Recovery Facility, with the composting by the community.*

Source: DKPP, 2014

Case Study 15.3 Figure 4 *Monitoring of the compost temperature at the Material Recovery Facility.*

Source: BEST, 2014



Case Study 15.3 Figure 5 *KIPRAH Voluntary Greenhouse Gas Emissions Reduction Program (VER) Numbers and Figures in Tangerang Selatan, June 2013–October 2014.*

Source: BORDA (2014)

KIPRAH VER PROGRAM: LOCAL ACTIONS FOR GLOBAL IMPACT

One of the most successful of the city's programs is the Voluntary Emission Reductions (VER) trading scheme under the KIPRAH (Kita-Pro-Sampah or We-Pro-Waste) Program, initiated by BORDA Indonesia and partners Lembaga Pengembangan Teknologi Pedesaan (LPTP) and Bina Ekonomi Sosial Terpadu (BEST) in 2006. The program is the first GHG emissions reduction community-based composting project worldwide, registered with the Gold Standard Foundation (www.goldstandard.org) in 2014. Carbon credits obtained as a result of verified emission reductions can be sold on the voluntary carbon market, thus contributing directly to international climate mitigation efforts.

KIPRAH VER promotes aerobic composting using an innovative bamboo aerator method, with a standard Measurement Reporting and Verification (MRV) method at the community level. Aerobic composting of organic waste avoids methane emissions that would result from burying the organic waste. One of the monitoring standards, measuring the compost temperature, is shown in Case Study 15.3 Figure 4. Currently nine MRFs in Tangerang Selatan are part of the VER program with significant amounts of GHG emission reduction in the Gold Standard verification process (see Case Study 15.3 Figure 5) under the partner area of BEST Tangerang Selatan.

LESSONS LEARNED

The goodwill and commitment of city government leaders, communities, and NGOs who have the vision to move forward and improve environmental quality and public health have motivated all sectors to be actively involved within the government's waste management programs. The city is committed to reaching its target of 20% reduced waste going into the landfill using RBs and MRFs. Tangerang Selatan also has the potential to become the Indonesian city with the highest GHG emission reductions from the community-based waste sector.

List of Abbreviations (terms in English).

BAPPEDA	*Badan Perencanaan dan Pembangunan Daerah* or Planning and Regional Development Agency
BEST	Bina Ekonomi – Sosial Terpadu (NGO) or Institute for Economic and Social Development
BLHD	*Badan Lingkungan Hidup Daerah* or Regional Environmental Agency
BORDA	Bremen Overseas Research and Development Association (NGO)
DKPP	*Dinas Kebersihan Pertamanan dan Pemakaman* or Department of Cleanliness, Parks and Cemetery
DTKBP	*Dinas Tata Kota Bangunan dan Pemukiman* or Department of City Planning Building and Settlement
LPTP	Lembaga Pengembangan Teknologi Pedesaan (NGO) or Foundation for the Development of Rural Technology

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Table 15.4 *GHG emissions (kg $CO_{2\text{-eq.}}$) from use of fuel for collection, transfer and transport of 1 ton of waste, calculated in the six different examples. Source: Fruergaard et al., 2009*

Example	Collection	Transfer	Transport	Total
1. Residual waste with 20 km of transport by truck	43–46	–	4–11	47–57
2. Residual waste with 20 km of transport by truck	5.0–5.5	–	4–11	9–17
3. Residual waste with 150 km of transport by truck	10–11	0.05–4.5	14–28	24–44
4. Recyclable paper with 2,000 km of transport by truck	6–11	0.05–4.5	182–380	189–396
5. Recyclable paper with 3,000 km of transport by diesel train	6–11	0.05–4.5	6–174	13–190
6. Recyclable materials with 10,000 km of transport by ship	100–300	0.10–8.9	29–59	129–368

Table 15.5 *GHG emissions (kg $CO_{2\text{-eq}}$) from provision and combustion of fuel used in waste collection and transport. Source: Fruergaard et al., 2009*

Type of process/emission	Emission factor range	Unit
Provision of diesel oil	0.4–0.5	kg $CO_{2\text{-eq.}}$/lt
Provision of gasoline	0.7	kg $CO_{2\text{-eq.}}$/lt
Provision of fuel oil (heavy)	0.4–0.6	kg $CO_{2\text{-eq.}}$/lt
Provision of fuel oil (light)	0.4–0.5	kg $CO_{2\text{-eq.}}$/lt
Provision of natural gas	0.2–0.3	kg $CO_{2\text{-eq.}}$/Nm^3
Combustion of diesel oil	2.7	kg $CO_{2\text{-eq.}}$/lt
Combustion of gasoline	2.3	kg $CO_{2\text{-eq.}}$/lt
Combustion of fuel oil (heavy)	2.9	kg $CO_{2\text{-eq.}}$/lt
Combustion of fuel oil (light)	2.7	kg $CO_{2\text{-eq.}}$/lt
Combustion of natural gas	2.2	kg $CO_{2\text{-eq.}}$/Nm^3
Provision of electricity	0.1–0.9	kg $CO_{2\text{-eq.}}$/kWh
Provision of heat (EU-25)	0.075	kg $CO_{2\text{-eq.}}$/MJ

tons of materials, avoiding 12 million tons of GHG and saving 6.3 million G J of energy (0.4 million barrels of oil).

15.4.4 GHG Emissions and Waste Treatment and Disposal Practices

15.4.4.1 Anaerobic Digestion

GHG emissions from anaerobic digestion facilities are generally limited to system leaks from gas engines used to generate power from biogas, fugitive emissions, and CO_2 from combustion methane, and during system maintenance. There are also possible traces of methane emitted during maturation of the solid organic output. Anaerobic digestion requires energy input but is generally self-sustaining and can make several contributions to climate change mitigation.

First, digesters capture biogas or landfill gas that would have been emitted anyway because of the nature of organic waste management at the facility where the digester is in operation. Second, the displacement of fossil fuel–based energy that occurs when biogas is used to produce heat or electricity is an important contribution. Finally, GHG emissions are also reduced when the nutrient-rich digester created from anaerobic digestion is used to displace fossil fuel–based fertilizers used in crop production. This digestate can make a natural fertilizer that is produced with renewable energy as opposed to fossil fuels (Bogner et al., 2007; Hoorweg and Bhada-Tata, 2012; Annepu, 2013).

Anaerobic digestion can be well-suited to source-separated food wastes, particularly in developing countries where MSW contains 50% or more of food wastes, once the technological challenge the method imposes is surmounted. A critical impediment to its adoption in the developing world is the cost of separate collection and the initial capital investment, which is more than US$500 per ton of installed annual capacity (Arsova, 2010). This is true to the extent that, even in rich countries, it is not adopted on a large scale since the energy yield is around 0.2 MWhe per ton of organic waste compared with waste-to-energy (WTE) high-efficiency plants that can reach 0.8 MWhe per ton if mixed waste is used (no need to collect separately).

15.4.4.2 Aerobic Composting

Aerobic composting refers to the degradation of organic waste by micro-organisms in a controlled environment and in the presence of oxygen to produce a stable product – compost. The process, which is ineffective for the management of MSW high in plastics, metals, and glass content, can directly emit varying levels of gases including nitrous oxide, depending on how the closed system is managed (Mohee and Bundhoo, 2015). A review of several studies show that MSW composting

Table 15.6 *GHG Emissions reductions and energy saving of benefits of recycling (Canada). Source: Recycling Council of Ontario, 2002*

Recyclables	Recycled (tons)	GHG Savings (tons of $CO_{2\text{-eq}}$)	Energy savings (GJ)	Equivalent of barrels of oil saved	Equivalent value of oil saved (based on $ 62/ barrel)
Newsprint	8,000,043	1,224,066	5,160,277	793,889	49,221,107
Cardboard & Boxboard	705,856	2,498,730	6,013,893	925,214	57,363,288
Mixed paper	1,519,958	6,657,416	24,030,536	3,697,006	229,214,343
Glass	339,132	40,696	569,742	87,653	5,434,460
Ferrous metals	808,596	970,315	10,196,396	1,568,676	97,257,927
Copper	5,369	22,067	385,011	59,232	3,672,413
Aluminum	51,737	336,808	4,519,744	695,345	43,111,407
PET- plastic	97,450	354,718	8,313,460	1,278,994	79,297,614
HDPE - plastic	54,816	125,528	3,531,231	543,266	33,682,514
Total	**4,382,957**	**12,230,344**	**62,720,290**	**9,649,275**	**598,255,072**

emits 0.12–9 kilograms methane per ton of treated waste and 0–0.43 kilogram N_2O-N per ton of treated waste (Sánchez et al., 2015).

Composting is suited as a waste management technology in developing countries that have a high portion of biodegradable waste, but to date composting is mostly practiced in developed countries. In 2010, the fraction of MSW composted in Austria was more than 30%, whereas in Belgium and the Netherlands, it was greater than 20% (European Environment Agency [EEA], 2013). Most composting processes tend to be unsuccessful in developing countries due to the composting of commingled instead of segregated MSW, resulting in poor-quality compost. Composting output, which can be used as a substitute for the primary production of fertilizers, provides environmental benefits, yet it is beset with problems of quality and market for the products (UNEP, 2006).

15.4.4.3 Waste-to-Energy

There are more than 800 WTE power plants worldwide producing electricity and district heating by combusting waste. In Switzerland, Japan, France, Germany, Sweden, and Denmark, more than 50% of the waste that is not recycled is sent to WTE industries thereby reducing the amount of waste disposed of in landfills to as little as 4% of the total waste generated (Be Waste Wise, 2013). Incinerators that do not generate energy are net energy users and contribute to GHG emissions. In that respect, incineration without energy recovery is not recommended (UNEP, 2010). Advanced thermal treatment technologies, such as gasification and pyrolysis, may emit fewer GHG emissions compared to mass-burn incineration, and even negative GHG emissions if the energy produced by these technologies is taken into account. This is clearly shown in the assessment of global warming potential from different treatment technologies in Aalborg. The shift to incineration technology with energy recovery significantly reduced about −400 $kgCO_2e$ per ton of waste, compared to the use of incineration without energy recovery, which emitted 251.5 per ton of waste (Habib et al., 2013).

15.4.4.4 Landfill Gas-to-Energy

Methane generated in landfills may be flared, which reduces emissions into the atmosphere. If captured, methane can be burned to produce energy, thereby offsetting emissions from fossil fuel consumption (EPA, 2006). These landfill sites with flaring and electricity generation emit much less GHGs than those without gas collection. A study of direct GHG emissions from South African landfill sites show that about 40–75 $kgCO_2e$ per ton of waste can be saved by disposing of MSW in landfill sites with flaring or energy recovery instead of general landfill sites (Friedrich and Trois, 2013).

Landfill gas-to-energy (LFGTE) is the most economical method to reduce GHG emissions from MSW when compared to all other treatment and disposal alternatives (see Table 15.7). LFGTE provides the highest potential to reduce GHG emissions at a cost of less than US$10 per $tCO_{2\text{-eq}}$. This potential rests mainly in non-OECD countries where financing waste management can provide many other co-benefits.

15.4.4.5 Landfilling

The organic content in waste sent to landfill (e.g., food, biomass, paper) naturally decomposes under anaerobic conditions.

Table 15.7 *Economic reduction potential of methane emissions from landfill waste by level of marginal costs for total GHG emission reduction assessed for the year 2030. Source: OECD, 2012*

CH4 reduction (Tg of CO_{2-eq})		USD/t CO_{2-eq}				
Category	**Region**	**0**	**10**	**20**	**50**	**100**
Anaerobic digestion	OECD	0	0	1	5	5
	EIT	0	0	0	20	24
	Non-OECD	0	0	30	68	95
	Global	0	0	31	94	124
Composting	OECD	0	0	0	0	3
	EIT	0	0	0	6	19
	Non-OECD	0	0	0	58	81
	Global	0	0	0	64	102
Mechanical Biological Treatment	OECD	0	0	0	0	0
	EIT	0	0	0	0	0
	Non-OECD	0	0	0	0	19
	Global	0	0	0	0	19
LFG recovery- energy	OECD	27	43	41	23	22
	EIT	56	29	15	0	0
	Non-OECD	328	368	306	138	43
	Global	411	440	362	162	65
LFG recovery- flaring	OECD	0	6	1	0	0
	EIT	0	17	0	0	0
	Non-OECD	0	12	0	0	0
	Global	0	34	1	0	0
Waste incineration with energy recovery[a]	OECD	124	222	237	266	266
	EIT	0	101	156	156	140
	Non-OECD	0	0	166	515	653
	Global	124	323	558	936	1,059
Total	OECD	151	270	280	295	296
	EIT	56	147	171	182	182
	Non-OECD	328	380	501	779	890
	Global	535	797	953	1,255	1,369

[a] Combustion of waste also causes fossil CO_{2-eq} emissions, which have been taken into account in the calculations, but this table only presents emissions savings from landfills. However, these emissions are typically overcompensated by the corresponding savings when waste-based energy replaces fossil fuels in the energy systems.

The decay, usually initiated by bacteria and microbes, can lead to the production and release of GHGs such as methane, carbon dioxide, and some trace gases that are environmentally unfriendly. Indeed, such emissions can persist for half a decade and more after waste has been disposal of (UNEP, 2006). The situation in most developing countries is worrying because most landfills do not include high-quality liners, leak detection leachate collection systems, or adequate gas collection and treatment systems (Hoorweg and Bhada-Tata, 2012). For biodegradable waste, landfills are the largest emitters of GHG compared to other treatment systems. As presented in Figure 15.5, the landfill option emitted nearly 1,200 kilograms of CO_2 for 1 ton of food waste in the European Union in 2008 while composting emitted negligible amounts of GHG. Further decreases in GHG emissions from treating biodegradable waste can be achieved from incineration, home composing, and anaerobic digestion.

15.5 Impacts of SWM on Climate Change

Generally, post-consumer waste is a small contributor to global GHG emissions, estimated at approximately 3–5% of total anthropogenic emissions or less than 50% with total emissions of approximately 1,300 $MtCo_2eq$ in 2005 (Bogner et al., 2008; UNEP, 2010) (see Table 15.8). The actual magnitude of these emissions in current terms is difficult to determine due to poor data on global waste generation, composition, and management as well as inaccuracies in emission models. The OECD nations, however, have an installed WTE capacity of more than 200 million tons of MSW and also 200 million tons of sanitary landfilling that either uses or flares an estimated 59% of the methane emitted. Developing countries, on the other hand, dispose of an estimated 900 million tons of MSW in nonsanitary landfills and waste dumps.

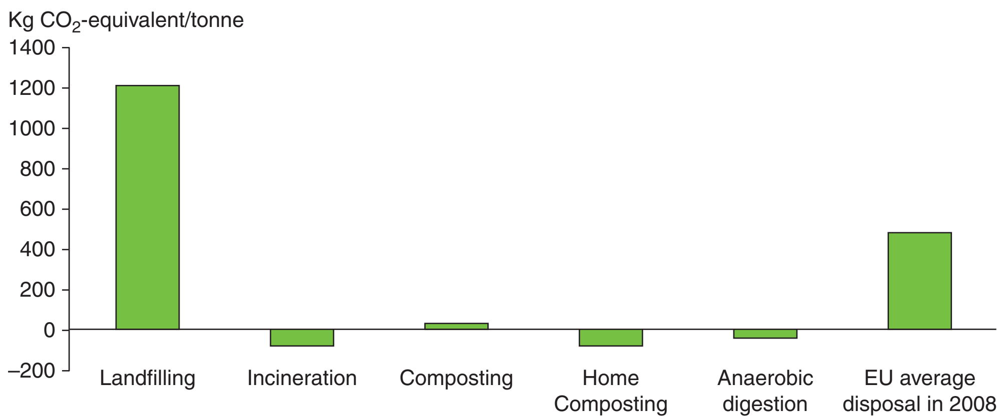

Figure 15.5 *Net emissions for different treatment options for biodegradable waste.*

Source: EEA, 2011

Table 15.8 *Trends for GHG emissions from waste using (a) 1996 and (b) 2006 IPCC inventory guidelines, extrapolations, and projections ($MtCO_2$-eq, rounded). Source: IPCC, 2007*

Source	1990	1995	2000	2005	2010	2015	2020	2030	2050
Landfill methane (CH_4)[a]	760	770	730	750	760	790	820		
Landfill CH_4[b]	340	440	450	520	640	800	1000	1500	2900
Landfill CH_4 (average of[a] and[b])	550	585	590	635	700	795	910		
Incineration CO_2[b]	40	40	50	50	60	60	60	70	80
Total GHG emissions	1120	1205	1250	1345	1460	1585	1740		

Notes: Emissions estimates and projections as follows:

[a] Based on reported emissions from national inventories and national communications, and (for nonreporting countries) on 1996 inventory guidelines and extrapolation (EPA, 2006).

[b] Based on 2006 inventory guidelines and BAU projection (Monni et al., 2006).

Total includes landfill CH_4 (average), wastewater CH_4, wastewater N_2O, and incineration CO_2.

15.5.1 Formal and Informal Recycling and Climate Change

Most developing countries face increasing challenges when it comes to waste recycling. While formal recycling programs appear to be the most plausible option, their applicability and practicality are complicated by a number of drawbacks such as technology, cost, and institutional inadequacies, among others (Potter et al., 2008). As a result, the most popular option is the use of informal and rudimentary approaches, mechanism, and practices where reusable and recyclable material are gathered at the individual, family, and household levels by poor scavengers who make a good business from their activities even if they are overly exploited by middlemen and well-organized pickers and unions/associations (Samson, 2009).

In terms of its livelihood generation potential, Potter et al. (2008) indicate that as many as 20,000 people live and work on municipal dumps in Kolkata, India, whereas Mexico City has some 15,000 such workers. Further research by Chaturvedi (2010) indicates that women and socially marginalized groups numbering up to 1.5 million people in India are engaged in waste picking; there are 18,000 *recicladores* in Bogotá, Colombia; 15,000 *clasificadores* in Montevideo, Uruguay; and 9,000 *cartoneros* in Buenos Aires, Argentina (Schamber et al., 2007). Table 15.9 presents the livelihood potentials of both formal and informal recycling in Asian cities.

The significance of the activities of informal recyclers and their operations lies not only in the reduction of waste to dumpsites – with its attendant environmental and health challenges – but also in their contribution in reducing GHG emissions. Tables 15.10, 15.11, and 15.12 present waste recovery rates and the carbon footprints of the formal and informal recycling sectors in seven cities.

Naturally, the activities of these formal and informal recycling sectors not only improve public health and sanitation but also guarantee environmental sustainability by way of reduced GHG emission. Additionally, the informal subsidy of SWM necessarily saves scare capital needed by city authorities for other pressing development issues. A recent UN report has regretted how some city and municipal authorities in developing countries continue to exploit waste gatherers who collect between 50% and 100% of MSW at no cost (UN-Habitat, 2010).

GHG emissions from the informal recycling sector are extremely low compared to formal collection systems. Informal recyclers use comparatively less motorized transportation and use numerous transfer points to collect and store recyclables for transportation. Some recommendable modes of waste collection used by informal recyclers are bicycles, tricycles, and other three-wheeled trolleys to collect waste from households. Some informal recyclers set up shop at the end of every street and are known in the locality so that the public can approach them whenever they have items that need to be salvaged. Some methods, like using non-motorized transportation for collection, can be emulated by formal systems, or the informal recyclers who perform such duties regularly can be integrated into formal systems. While dry recyclable items can be stored to optimize

Table 15.9 *Informal and formal livelihoods in six cities. Source: Scheinberg et al., 2010*

City/Indicator	Cairo	Cluj	Lima	Lusaka	Pune	Quezon
Livelihoods in informal waste sector (persons)	33,000	3,226	17,643	480	8,850	10,105
Livelihoods in the formal waste sector (persons)	8,834	330	13,777	800	4,545	5,591
Ratio of persons working in the informal sector to those in the formal sector	3.7	9.8	1.3	0.6	1.9	1.8
Average informal workers' earnings (€/year)	2.721	345[a]/2.070	1.767	586	1.199	1.667

[a] Represents actual earnings from about 50 days of labor per year of €345 multiplied by 6 for purposes of comparison with other cities.

Table 15.10 *Waste recovery rates in seven cities by sector. Source: Scheinberg et al., 2010*

Waste recovery rate in seven cities (CWG-GIZ/Scheinberg et al., 2010).	Belo Horizonte (Brazil)	Canete (Peru)	Delhi (India)	Dhaka (Bangladesh)	Managua (Nicaragua)	Moshi (Tanzania)	Quezon City (Philippines)
Recovered by formal sector (%)	0.10%	1%	7%	0%	3%	0%	8%
Recovered by informal sector (%)	6.90%	11%	27%	18%	15%	18%	31%
Total recovered all sectors (tons)	145,134	1,412	841,070	210,240	78,840	11,169	287,972

transportation, it is not suitable for wet or mixed waste, which is generally collected by the formal municipal collection systems. Wet or mixed waste cannot be stored for long due to decomposing materials and the risk of disease.

Existing and functioning informal recycling systems in developing countries have to be integrated into formal systems to reduce GHG emissions from SWM. Additionally, diversifying the livelihoods of waste collectors and waste recyclers is sine qua non to the economic and social empowerment of women, children, and other marginalized groups who may be engaged in that business. This can prove significantly crucial in the global poverty alleviation agenda (Scheinberg et al., 2010).

Table 15.11 *Comparison of material recovery by formal and informal sector in six different cities. Source: Scheinberg et al., 2010*

	Formal sector		Informal sector	
City	**Tons**	**% of total**	**Tons**	**Percent of total**
Cairo	433,200	13	979,400	30
Cluj	8,900	5	14,600	8
Lima	9,400	0.3	529,400	19
Lusaka	12,000	4	5,400	2
Pune	–	0	117,900	22
Quezon City	15,600	2	141,800	23

15.5.2 Landfills and Climate Change Mitigation

There are two major strategies to reduce landfill methane emissions: implementation of standards that require or encourage its recovery and a reduction in the quantity of biodegradable waste that is landfilled (Price, 2001). In some instances, methane reduction efforts are complicated by countries that wish to trade their recovery standard for economic gains. This is particularly true in the case of the United Kingdom where the Non-fossil Fuel Obligation, which was meant to generate electricity per a certain standard, instead led to a compromise in the 1980s and 1990s. Also, periodic tax credits in the United States have provided an economic incentive for landfill gas utilization.

It is thought that landfill methane recovery across the developing world will likely increase in coming decades primarily because of improved and/or controlled waste disposal/management practices. And, with the emergence of the CDM that

Table 15.12 *Comparison of carbon footprint by formal and informal sector in cities. Source: Scheinberg et al., 2010*

	Formal sector		Informal sector	
City	**GHG (tons $CO_{2\text{-eq}}$)**	**Total net cost (benefit) of GHG emissions (€/year)**	**GHG (tons $CO_{2\text{-eq}}$)**	**Total net cost (benefit) of GHG emissions (€/year)**
Cairo	1,689,200	16,244,800	–28,900	–277,500
Cluj	103,600	1,295,300	–38,200	–478,000
Lima	448,500	4,313,400	–496,700	–4,776,800
Lusaka	25,800	247,700	–57,700	554,600
Pune	210,600	2,025,000	–295,000	–2,837,200
Quezon City	472,800	4,546,700	–249,200	–2,397,000

Box 15.4 Income-Generating Potential of Waste Pickers

The amount of income earned by waste pickers varies almost in tandem with the country's minimum wages as well as with the type of work that men and women do. In most instances, up to 91% of those engaged in the informal activities overtly or covertly depend on incomes from scavenging, as in the case of Cairo, Egypt (Scheinberg et al., 2010). In Belgrade, waste pickers may earn an average amount of US$100 per month (Simpson-Hebert et al., 2005) as compared to a poverty line of US$105 or 80 euros in that country. By contrast, waste pickers in Cambodia could go home with a paltry US$1 a day (International Labor Office [ILO/IPEC], 2004). Relatedly, in Santa Cruz, Bolivia, about 59% of waste pickers earn below the minimum wage, while Brazilian and Mexican waste pickers earn more than the minimum wage. Crivellari et al. (2008) indicate that about 34% of waste pickers in Brazil earn about 1.01–1.50 times the minimum wage, whereas men earn more than women in all age groups (Crivellari et al., 2008).

champions the course of development through environmentally friendly practices such as carbon sink and sequestration, the future could not be any brighter (Sceinberg et al., 2010).

Due to many countries facing challenges on the basic way forward to maximize recycling and materials recovered, the selection of truly efficient and sustainable waste management strategies is paramount. To achieve appreciable GHG emissions mitigation, the elimination of open dumping sites is an absolute priority (see Table 15.14).

15.5.3 Climate Change Adaptation and SWM

Scholarly literature on the impacts of climate change on SWM is limited. However, a number of studies have been carried out in recent years by the development community showing that climate change can significantly impact SWM services both directly and indirectly (Bebb and Kersey, 2003; USAID, 2012). It can directly affect SWM through the impacts to the waste management infrastructure and, indirectly, through the changes that would occur to the surrounding environment. For example, elevated temperatures and changes in hydrology could increase odor, litter, and decomposition rate, and may necessitate more frequent waste collection and better landfill management (to prevent leachate, landfill degradation). Similarly, extreme climate events (e.g., flooding, rainfall, erosion, sea level rise, storm surge) could affect the critical infrastructure (transport means, buildings, machinery) necessary for waste collection, transfer, disposal, and recycling (Bebb and Kersey, 2003). Table 15.13 shows potential ways in which the impacts of climate change affect waste management. These are just examples; the impacts would differ from city to city depending on the extent of impact, location, current practices of waste management, and prevailing infrastructure. Therefore, accessing the risks of climate change to waste management processes and sites at the early stage is very helpful.

Table 15.14 further shows the vulnerability of various waste management technologies and practices along with adaptation and mitigation implications and other sustainability dimensions (IPCC, 2006).

Table 15.13 *Climate change impact to solid waste management sector. Source: USAID, 2012*

	Collection	Processing	Disposal
Temperature change	Increased odor pest activity requiring more frequent waste collection Overheating of collection vehicles requiring additional cooling capacity. including to extend engine life	Overheating of sorting equipment	Altered decomposition rates Increased maintenance and construction costs due to thawing permafrost Increased risk of fire at disposal sites
	Greater exposure of workers to flies, which are a major cause of infectious diseases (flies breed more quickly in warm temperatures and are attracted to organic waste)		
Precipitation change	Flooding of collection routes and landfill access roads, making them inaccessible Increased stress on collection vehicles and workers from waterlogged waste	Increased need for enclosed or covered sorting facilities	Increased flooding in/around sites Increased leachate that needs to be collected and treated Potential risk of fire if conditions become too dry and hot
Sea level rise	Narrowed collection routes Potentially increased waste in a concentrated area as people crowd into higher elevations within an urban area	Damage to low-lying processing facilities Increased need for sorting and recycling to minimize waste storage needs	Deterioration of impermeable lining Water infiltration of pit leading to possible overflow of waste
	Permanent inundation of collection, processing, and disposal infrastructure		
Storm surge	Temporary flooding of and diminished access to roadways, rails, and ports for waste collection, sorting, and disposal Closure of facilities due to infrastructure damage		
Extreme wind	Dispersal of waste from collection sites, collection vehicles, processing sites, and landfills Reduced access to collection and landfill access routes due to damage and debris		

Table 15.14 *Summary of adaptation, mitigation, and sustainable development issues for the waste sector. Source: IPCC, 2006*

Technologies and practices	Vulnerability to Climate change	Adaptation implications and strategies to minimize emissions	Sustainable development dimensions: Social	Economic	Environmental	Comments
Recycling, reuse and waste minimization	Indirect low vulnerability or no vulnerability	Minimal implication	Usually positive Negative for waste scavenging without public health or safety controls	Positive Job creation	Positive Negative for waste scavenging from open dumpsites with air and water pollution	Indirect benefits for reducing GHG emissions from waste Reduces use of energy and raw materials. Requires implementation of health and safety provisions for workers
Thermal processes including incineration, industrial co-combustion, and more advanced processes for waste-to-energy (e.g., fluidized bed technology with advanced flue gas cleaning)	Low vulnerability	Minimal implications Requires source control and emission controls to prevent emissions of heavy metals, acids gases, dioxins and other air toxics	Positive Odor reduction (non-CH_4 gases)	Positive Job creation Energy recovery potential	Positive Negative for improperly designed or managed facilities without air pollution controls	Reduces GHG emissions relative to landfilling Costly, but can provide significant mitigating potential for the waste sector, especially in the short term Replaces fossil fuels
Aerobic biological treatment (composting) **Also a component of mechanical-biological treatment (MBT)**	Indirect low vulnerability or positive effects: Higher temperatures increase rates of biological processes (Q_{10})	Minimal implications or positive effects Produces CO_2 (biomass) and compost Reduces volume, stabilizes organic C, and destroys pathogens	Positive Odor reduction (non-CH_4 gases)	Positive Job creation Use of compost products	Positive Negative for improperly designed or managed facilities with, odors, air and water pollution	Reduces GHG emissions Can produce useful secondary materials (compost) provided there is quality control on material inputs and operations Can emit N_2O and CH_4 under reduced aeration or anaerobic conditions
Anaerobic biological treatment (anaerobic digestion) **Also a component of mechanical-biological treatment (MBT)**	Indirect low vulnerability or positive effects: Higher temperatures increase rates of biological processes	Minimal implications Produces CH_4, CO_2, and biosolids under highly controlled conditions Biosolids require management	Positive Odor reduction (non-CH_4 gases)	Positive Job creation Energy recovery potential Use of residual biosolids	Positive Negative for improperly designed or managed facilities with, odors, air and water pollution	Reduces GHG emissions CH_4 in biogas can replace fossil fuels for process heat or electrical generation Can emit minor quantities of CH_4 during start-ups, shutdowns and malfunctions
Sanitary landfilling with landfill gas recovery and utilization	Indirect low vulnerability or positive effects: Higher temperatures increase rates of microbial methane oxidation rates in cover materials	Minimal implications May be regulatory mandates or economic incentives Replaces fossil fuels for process heat or electrical generation	Positive Odor reduction (non-CH_4 gases)	Positive Job creation Energy recovery potential	Positive Negative for improperly managed sites with air and water pollution	Primary control on landfill CH_4 emissions with >1,200 commercial projects Important local source of renewable energy: replaces fossil fuels Landfill gas projects comprise 12% of annual registered CERs under CDM. Oxidation of CH_4 and NMVOCs in cover soils is a smaller secondary control on emissions

CDM, Clean Development Mechanism; CER, certified emissions reductions; CH_4, methane; CO_2, carbon dioxide; GHG, greenhouse gas; N_2O, nitrous oxide; NMVOCs, non-methane volatile organic compounds

15.6 Carbon Market and Finance for GHG Mitigation from Waste

For an effective integrated solid waste management program, behavioral, technological, and management elements are essential, which necessitates new and innovative policies, better institutional coordination, and effective financial arrangements. Some of the policy strategies, which are also linked to financial mechanisms, are shown in Table 15.1. Different modes of financing for waste management are possible, however, in the context of climate change mitigation, and many studies in the scholarly as well as the development community have already shown that this sector is a cost-effective and "low-hanging fruit" in the entire portfolio of climate change mitigation options. Therefore, in climate change–related projects and financing systems, the waste sector has attracted many projects (see Figure 15.6). In the global architecture of carbon markets and financing, the CDM, a flexible mechanism of the Kyoto Protocol, is prominent SWM project type. By the end of 2012, issued carbon credits (CERs) from 407 landfill gas projects under CDM amounted to 71 million.[2] Potdar et al. (2015) reported a total of 350 SWM CDM projects globally (by May 2015), of which 102 CDM projects (12.8 mn tCO_2eq) were in China followed by 45 projects in Brazil (10.6 mn tCO_2), and 28 projects in Mexico (3 mn tCO_2e).

Composting, anaerobic digestion, WTE combustion, landfill gas capture, and flaring are all approved for CDM credits. Even though studies show that thermal processes potentially and efficiently exploit the energy value of post-consumer waste, the high capital investment of WTE plants invariably restricts its application in many less endowed countries (Bogner et al., 2007). It must be added that, at this time when the international market is uncertain, it is continual traction at the regional and subnational levels that shows some promise for the future.

15.7 Conclusion

Consistently increasing generation of MSW as a result of an increasing urban population and a rising standard of living has resulted in increasing amounts of biodegradable organic carbon and, by extension, GHG emissions. Implementing integrated waste management will push both the private and public sectors to rework the management process to decrease CO_2 emissions from the energy used for solid waste transport as well as to reduce methane and other non-CO_2 GHGs from landfills. This chapter has described many options for reducing GHG from the waste sector. There is a dire need to facilitate a shift from "waste management" to "resource efficiency," a paradigm shift that captures the entire value chain, thus merging the concept of sustainability and its subcomponents (e.g., the hierarchy) into programs that are effective across multiple sectors, disciplines, communities, and professions. In the case of cities in developed countries, continuous attempts are being made to divert waste from landfills to some advanced recycling facilities but the costs of environmental protection at treatment and disposal sites have also increased. Developing countries may lack access to such advanced technologies. However, technologies must be sustainable in the long term, and there have been many examples of advanced, but unsustainable, technologies for managing MSW that have been implemented in developing countries.

A number of economic, regulatory, and information-based policy instruments are available to implement these options to

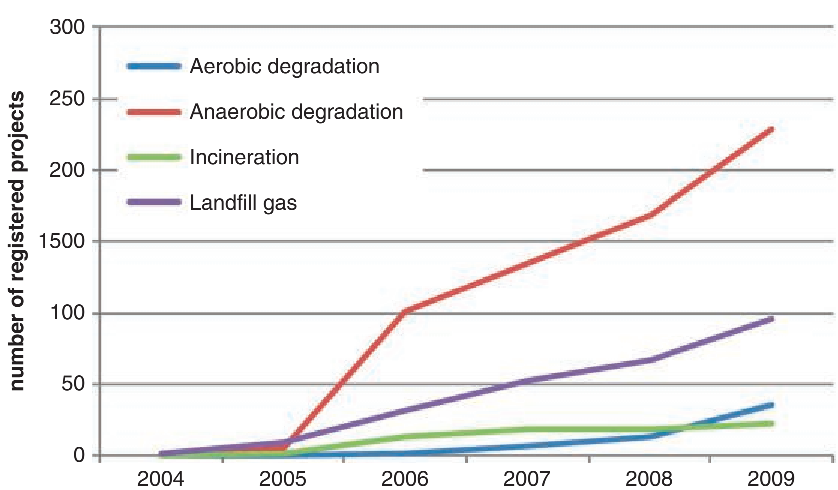

Figure 15.6 *Progression of number of waste-related projects with the status "registered" under the UN Framework Convention on Climate Change (UNFCCC) clean development mechanism between 2004 and 2009 according to the technology used (assessment of 400 out of 456 published projects).*

Source: Seibel et al., 2013

2 http://www.cdmpipeline.org/cdm-projects-type.htm

municipal government. Some of these instruments are extended producer responsibility (EPR), deposit-refund systems, landfill/incineration taxes, pay-as-you-throw (PAYT) fees, bans and restrictions (e.g., a landfill ban), mandatory source separation, and labeling and product information disclosure. To institute any of these measures, municipal authorities cannot work in isolation; they must involve all stakeholders in planning, implementing, and monitoring the changes. Successful cities (Vienna) have demonstrated a range of good practices – consultation, communication, and involvement with users; participatory and inclusive planning; inclusivity in siting facilities; and institutionalized inclusivity – that constitute the solid waste "platform." A strong and transparent institutional framework is an essential proxy indicator of good governance in solid waste.

One of the major hindrances, one that jeopardize improvements in waste management especially in developing countries, is lack of capital. It has been estimated that MSW management consumes between 3% and 15% of the total recurrent municipal budget, or between 0.1% and 0.7% of the per capita GDP. Recent advances in the carbon market and in carbon financing have provided opportunities to the waste sector, but the process has slowed in the past 2 years as stakeholders wait on the outcome of the UNFCCC's COP21 in December 2015. The prospect remains high, however, for further development of carbon markets and finance instruments.

It goes without saying that to achieve appreciable GHG emissions mitigation, the selection of truly efficient and sustainable waste management strategies is paramount. Clear budgets and lines of accountability are essential. Above all, it needs the political will to see waste management as a key component in the infrastructure of modern life. And people have to be prepared to pay for proper waste management systems. Until the benefits of good waste management are recognized, good systems will not be developed, people will not pay, and waste will continue to be uncollected or dumped. We face huge challenges in many cities, but the basic way forward is to maximize the recycling of materials, which has been achieved in many countries through the informal sector, and to maximize WTE or landfilling with energy recovery of residual waste. The elimination of waste dumps is an absolute priority.

Case Study 15.4 Sustainable Waste Management: The Successful Example of Vienna

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Keywords	Municipal waste management, effective, waste avoidance strategies
Population (Metropolitan Region)	1,791,298 (Comet, 2015)
Area (Metropolitan Region)	995,73 km² (Wien.at, 2015)
Income per capita	US$45,230 (World Bank, 2017)
Climate zone	Dfb – Continental, without dry season, warm summer (Peel et al., 2007)

Vienna holds the international top position regarding separate collection and sustainable waste management. This was achieved not only through Vienna's long-term planning of waste management and waste avoidance strategies, but also through environmental awareness training for children and adults (City of Vienna, 2015). In 2013, 1 million tons of municipal solid waste (MSW) was produced, 35% of which was source separated, a method that started in early 1980s and, by early 1990s, effectively covered the entire city. In the city of Vienna, there are 200,000 containers for recyclables, 19 waste collection centers, and 112 mobile and stationary collection points for hazardous waste (Thon, 2015). In addition to the waste recycling and utilization industry, measures for waste avoidance also influence collection: thus waste collection centers also accept functioning used appliances and similar items, which are then sold at nominal prices at a bazaar organized by the municipality. Vienna's toy collection campaign with its own specially designed containers, introduced in 2006, is another example of a collection scheme developed to prolong the useful life of products.

Additionally, the City of Vienna complies with the principles of short distances and autonomous disposal, thus making a valuable contribution to environmental protection. Biogenic waste is fully treated on Vienna's municipal territory, and the Viennese population benefits from all results of waste processing, such as high-quality compost, electricity, and district heating. Moreover, the waste-to-energy residues are processed, the metals extracted have significant value, and the mineral fraction is extensively used as secondary recycled aggregate, predominately as a sub-base and capping material in numerous civil engineering applications. Financing for the collection and treatment of all municipal waste is based on the residual waste fraction in order to create an incentive for separate waste collection (Comet, 2015; Thon, 2015). Thus, property owners are charged a quarterly waste management fee calculated from the volume of the residual waste containers installed on their properties and the frequency of bin emptying. The more material collected separately, the smaller the container volume that needs to be installed and the lower the cost (City of Vienna, 2015).

The minimum container capacity for residual waste is 120 liters; for hygienic reasons, every residual waste container must be emptied at least once a week. The collection and treatment of packaging material, used electrical appliances, and batteries is financed via manufacturers and importers according to the principle of manufacturer responsibility. Vienna has used three distinct initiatives to help reduce consumer waste and two additional initiatives for business wastes (see European Commission, 2012):

- *Web Flea Market*: An Internet-based exchange platform for consumer goods, construction tools and materials, and gardening equipment
- *Repair and Service Center (RUSZ):* Twenty-three local small repair shops provide affordable repair services for electrical household appliances and break down appliances for material recycling
- *Promotion of lifestyle change*: Encouraging spending on services and culture instead of material goods
- The city targets business waste through the following two measures:
- *The ÖkoBusinessPlan (EcoBusiness Plan)*: Targets small and medium-sized enterprises (SMEs). Launched in 1998 by Vienna metropolitan authorities, the initiative provides subsidized cleaner production and eco-efficiency consulting services to Vienna businesses.
- *OekoKauf Wien (EcoPurchasing Vienna)*: The City of Vienna spends around €5 billion on goods annually. This initiative has developed guidelines for ecologically sound purchasing methods.

The RUSZ centers repair approximately 400 tons of appliances annually, and the Internet Flea Market sells 450 tons of used appliances. The Vienna authorities calculate that about 11,000 tons of waste is saved through the RUSZ centers, while the flea market saves around 1,000 tons of waste annually. Since 1998, the ÖkoBusinessPlan has advised more than 600 businesses and helped to save an estimated €34 million, with more than 100,000 tonnes of waste prevented catalogues for the green public procurement of some 60 product groups.

In recent years, numerous waste-related measures implemented in Vienna have contributed to a reduction in climate-relevant emissions. Vienna's waste management system generates 130,000 tons of CO_2 credits. While waste treatment in 2010 triggered the generation of 420,000 tons of CO_2 equivalents, the emission volume avoided totaled 550,000 tons. This was made possible by the generation of district heat from residual waste incineration, the fermentation of kitchen scraps at Vienna's biogas plant, and waste separation and recycling activities, as well as the use of compost in organic farming. Projections for 2020 from the city of Vienna show a further decrease of CO_2-eq by approximately 650,000 tons. For the City of Vienna and all municipal actors concerned with waste management, active climate protection will remain a central task.

Annex 15.1 Stakeholder Engagement

Conscious efforts were made to engage some of the key stakeholders responsible for adapting infrastructure in respect of planning, implementation, monitoring, and evaluation of solid waste prevention, collection, and disposal initiatives that can impact on future climate. The challenge related to the variety of formal and informal actors in the management of solid waste at different spaces and scales, including the various ministerial, regional, and local authorities' advisory panels, and community- and faith-based organizations. To reach this multiplicity of stakeholders, we relied on in-depth interviews, focus group discussions, participatory events (forums), and interactive workshops. We also made use of knowledge exchange groups and social media engagements (including online discussions groups/forums) as well as academic publications (e.g., reports, policy briefs). Apart from highlighting the challenges posed by the multiplicity of actors in the industry, our engagements also revealed the catalytic and supportive role played by international organizations notably the World Bank, the World Health Organization, and the UN Development Program in bridging the gap between long- and short-term solid waste infrastructure provision.

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