Chapter 1
Waste Management Strategies; the State of the Art

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List of Abbreviations

MSWM	Municipal Solid Waste Management
MSW	Municipal Solid Waste
SWM	Solid Waste Management
WM	Waste Management
MRF	Materials Recovery Facility
RDF	Refuse-derived Fuel
SRF	Solid Recovery Fuel
AD	Anaerobic Digestion
LCA	Life Cycle Assessment
EU	European Union
e-waste	Electronic Waste
EPA	Environmental Protection Agency
ABS	Acrylonitrile butadiene styrene
HIPS	High impact polystyrene

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M. Tabatabaei and H. Ghanavati (eds.), *Biogas*, Biofuel and Biorefinery
Technologies 6, https://doi.org/10.1007/978-3-319-77335-3_1

PC	Polycarbonates
PVC	Polyvinyl chloride
PET	Polyethylene terephthalate
ASTM	American Society for Testing and Materials
TFS	Transfrontier shipment
VOCs	Volatile Organic Compounds
C/N ratio	Carbon to Nitrogen Ratio
CH_4	Methane
CO_2	Carbon Dioxide
N_2	Nitrogen
H_2	Hydrogen
H_2S	Hydrogen Sulphide
NH_3	Ammonia
VS	Volatile Solids
BOD	Biological (Biochemical) Oxygen Demand
COD	Chemical Oxygen Demand
UNIDO	United Nations Industrial Development Organization
t	Tonne
BMP	Biochemical Methane Potential
OM	Organic Material
LAC	Latin America and Caribbean

1.1 Waste Management; A Conceptual Approach

Maximizing resource (material and energy) recovery and minimizing environmental impacts such as contribution to the global warming are two of the very first and important objectives in the solid waste management (SWM) sector, which is considerably developed over the past century (Habib et al. 2013). In fact, the way solid wastes have been managed over the history of human civilization has faced a tremendous level of change, shifting from the focus on public cleansing of the cities to modern waste management strategies. This happened mainly due to the lifestyle changes and swift industrialization process all around the world, which has led to the introduction of new materials and the consequent changes in the types and composition of the generated wastes (Christensen 2011).

It is crucial to note that the definition of the term “waste” is totally subjective and depends on various factors including time, location, income level, state, and personal preference (Table 1.1). In another words, culture, climate, religious, ethnic background, as well as economic abilities could affect what would be defined as waste. For instance, The European Union (EU) defines waste as “any substance or object which the holder discards or intends or is required to discard.” This is also supplemented with various examples of items and materials that can be considered as waste within a long list entitled “European Waste Catalogue” (Christensen 2011). Similarly, the term “management,” based on the Basel Convention, means

Table 1.1 Influential factors on the definition of the term “waste” adopted from Christensen (2011)

Time	• During scarcity, e.g., war time and embargo, repairing an item may become economical, since buying a new version may be costly or hard to achieve
Location	• For example, the feasibility of using food wastes for animal feeding in rural *vs.* urban areas
State	• Regarding an item's state (price, age, and type of damage), it may be repairable
Income Level	• The higher the income, more food or other stuffs would be likely to be discarded
Personal Preference	• Waste to an individual may not be regarded as waste to another individual

collection, transport, and disposal of hazardous wastes or other wastes, including after-care of disposal sites (UNEP 2014).

As an example of a type of waste and its subsequent relevant issues, electronic waste (e-waste) would be a good option. E-waste, as one of the rapidly growing waste pollution problems worldwide, can seriously contaminate the environment and threaten human health by a variety of toxic substances. Many protocols for this type of waste have been introduced across countries focusing on management, disposal, as well as reprocessing and reutilization of these wastes as raw materials. Overall, developing eco-design devices, proper collection of e-wastes, safe recovery and recycling of materials, disposal of e-wastes by suitable techniques, raising awareness of the impacts of e-waste, and forbidding the transfer of used electronic devices to developing countries are the dominant factors to be considered to accomplish a successful e-waste management. In spite of that, heavy movements of hazardous wastes, especially e-wastes into Asia, notably India, China, and Pakistan have been observed contrary to the instructions set forth by international protocols, e.g., The Basel Convention (Pariatamby et al. 2015; Kiddee et al. 2013). Almost 5% of the total waste volume generated globally is contributed by e-wastes and, according to the Environmental Protection Agency (EPA), 30–40 million personal computers are estimated to reach their “end-of-life” each year. This means that a huge amount of hazardous materials is ready to be added to the environment, while a variety of valuable materials and minerals can be recovered. There are a number of companies around the world utilizing proper technologies for recovering largely ferrous metals, aluminum, copper, circuit boards, as well as plastics, acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), polycarbonates (PC), and ABS-PC from e-wastes (CP Group 2017).

In the year 2012, approximately 1.3 billion t of MSW were generated globally, and this figure is expected to rise to approximately 2.2 billion t by the year 2025

(Rajaeifar et al. 2017). Regarding the environmental impacts, soil, water, and especially air are prone to be enormously influenced by the unsafe disposal of wastes (Pawłowska 2014). Groundwater pollution at landfills, air quality affected by gaseous emissions through incineration, as well as metals remained in soil and crops after the utilization of MSW-oriented compost are some of the examples of contaminations caused by unsafe SWM. Such consequences have led to the implementation of much more strict regulations and laws in the waste management sector to meet the concepts as sustainability (Christensen 2011).

Sustainability, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," (Commission 1987) has environmental, social, and economic dimensions with a focus on long-term issues. As a matter of fact, this definition states that each generation has to take the responsibility of their very own-generated problems and try to solve them with the help of local solutions. To do so, there are quite a few protocols covering different aspects of waste management including The Basel Convention, The Montreal Protocol, The Kyoto Protocol, and The Aarhus Convention along with a number of powerful tools such as LCA introduced to perform feasibility studies.

Moreover, considering the above-mentioned issues as well as the complexity and high expenses of waste management in the modern days, new strategies and systems have also been introduced to this sector (Christensen 2011). Among the most important strategies in SWM throughout the world, considering the waste hierarchy (Fig. 1.1), 3R—"reduce, reuse, and recovery"—is one-of-a-kind, frequently used

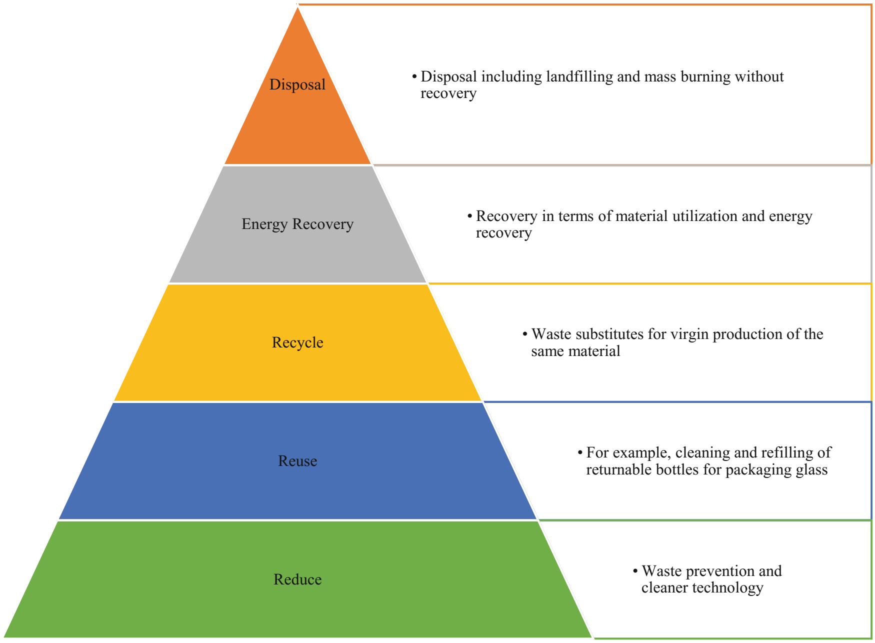


Fig. 1.1 Waste hierarchy adopted from Christensen (2011) and Richards and Taherzadeh (2016)

by the Western world and some parts of the Asia (especially Japan) since early 1980s (Richards and Taherzadeh 2016). MSW through the implementation of a systematic management can serve as a precious resource for different purposes (World Energy Council 2013). It is worth mentioning that resource (material and energy) recovery, as an important step in the waste hierarchy, implies not only the utilization of waste to produce materials and harvest different forms of energy carriers, but also the efforts in the context of avoiding environmental impacts from production of raw materials and simultaneously waste disposal (Christensen 2011). It is also critical to highlight waste collection as well, which contributes a considerable part of WM expenses (usually about half of the costs of a typical waste management system). In better words, within a comprehensive WM system, all factors from the point of waste collection to final disposal have to be considered (Dubanowitz 2000).

Waste management systems can be divided into six different categories namely Landfilling, Composting, MRF, AD, Incineration, and RDF/SRF. Each system has its own characteristics with a wide range of Waste-to-Energy (WtE) technologies offered around the world. In general, WtE technologies can be defined as any waste treatment processes that create energy from a waste source in any forms of energy carrier, i.e., electricity, heat, or transportation fuels (World Energy Council 2013). Based on a report by World Energy Council, increase in the amount of generated waste, high costs of energy, growing concerns of environmental issues, and restricted landfilling capacities are the summarized main drivers for the growth in WtE market in the past decades (World Energy Council 2013). In 2013, the global WtE market faced a growth of 5.5% with respect to its preceding year and reached a value of 25.32 billion USD. Among the various WtE technologies, thermal energy conversion was at the top and accounted for 88.2% of total market revenue in the same year (World Energy Council 2016).

It should be highlighted that while a system with a particular technology is suitable for a region, it may lead to a disaster for another region. Therefore, a comprehensive investigation on different influential factors including demographic, meteorological, and social background, as well as industrial zones, water, and electricity grid availability has to be conducted prior to the decision-making step by well-educated experts.

1.1.1 Global Status

The degree of industrialization, life style, local climate, and economic development are the prominent influential factors on MSW generation rates. As a rule of thumb, the greater the population, the higher the economic development, and the higher the rate of urbanization, all will lead to a higher rate of municipal solid waste production in addition to the change in its composition and treatment technologies (World Energy Council 2013). In this section, population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1})

as well as changes in the contribution of different MSWs treatment options in various parts of the world (i.e., The United States of America (USA), EU-27, Australia, Japan, Iran, Africa, Middle East, East Asia and the pacific region, Eastern Europe and central Asia, China, as well as Latin America and the Caribbean) have been graphically presented (Figs. 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, and 1.11).

As it can be seen from the above figures, various strategies are applied in different regions and countries depending on their distinct local conditions. For example, a 4.7% increase in the amount of incinerated waste (i.e., from 72.02% in 1990 to 76.72% in 2010) was recorded in Japan. On the other hand, the total generated waste in Japan was decreased by 9.8%, while MSW generation per capita was also reduced from 1.11 kg person^{-1} day^{-1} to 0.97 kg person^{-1} day^{-1} over the same time period. These promising improvements could be attributed to technological developments along with implementation of appropriate waste management strategies, laws, and regulations (Rajaeifar et al. 2017).

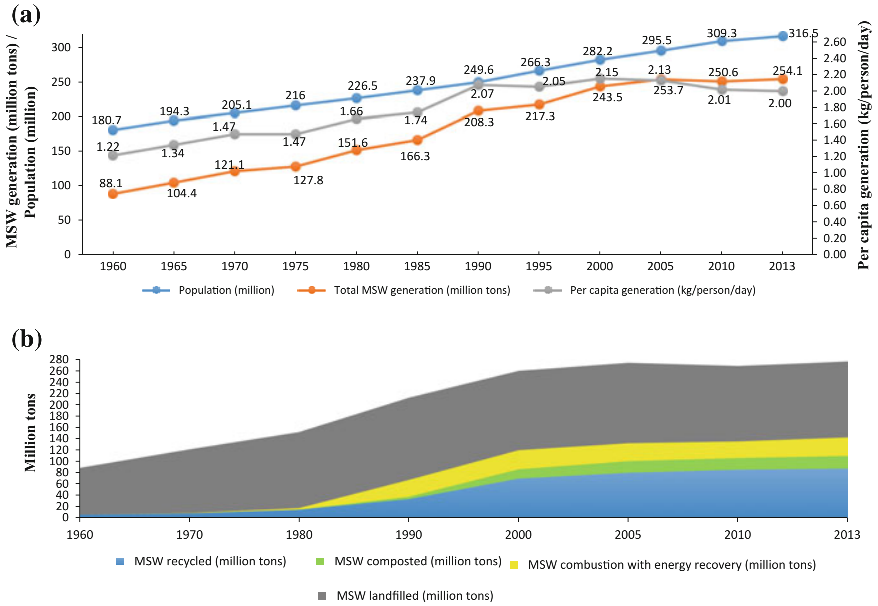


Fig. 1.2 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in the USA (1960–2013). **b** Changes in the contribution of different MSWs treatment options in the USA (1960–2013) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

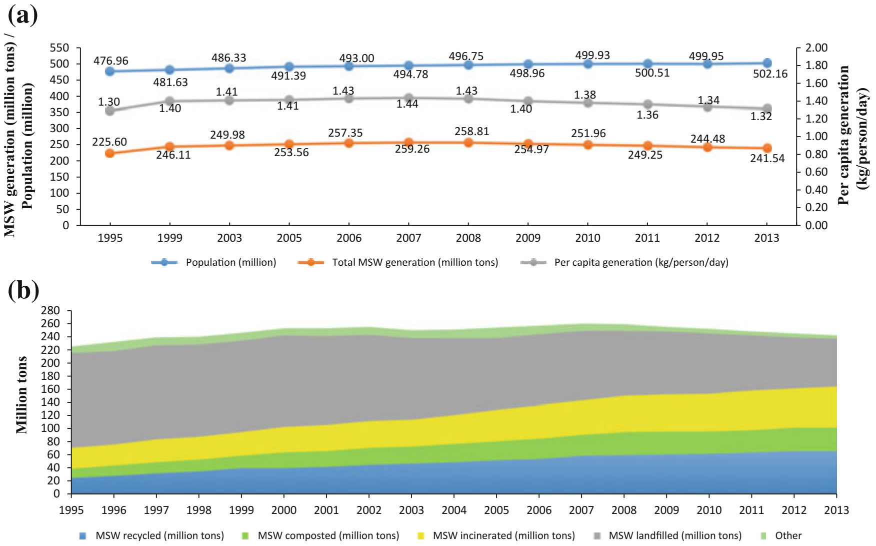


Fig. 1.3 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in the European Union (EU)-27 (1995–2013). **b** Changes in the contribution of different MSWs treatment options in the European Union (EU)-27 (1995–2013) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

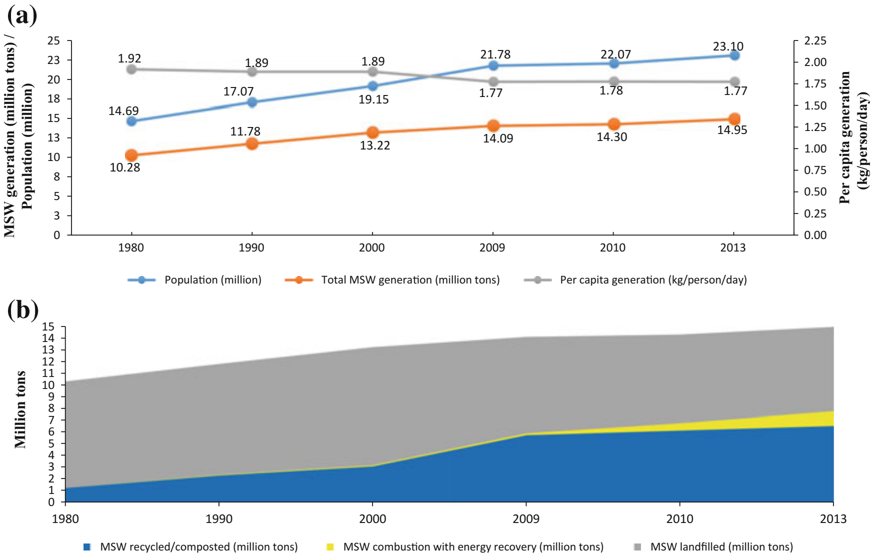


Fig. 1.4 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in Australia (1980–2013). **b** Changes in the contribution of different MSWs treatment options in Australia (1980–2013) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

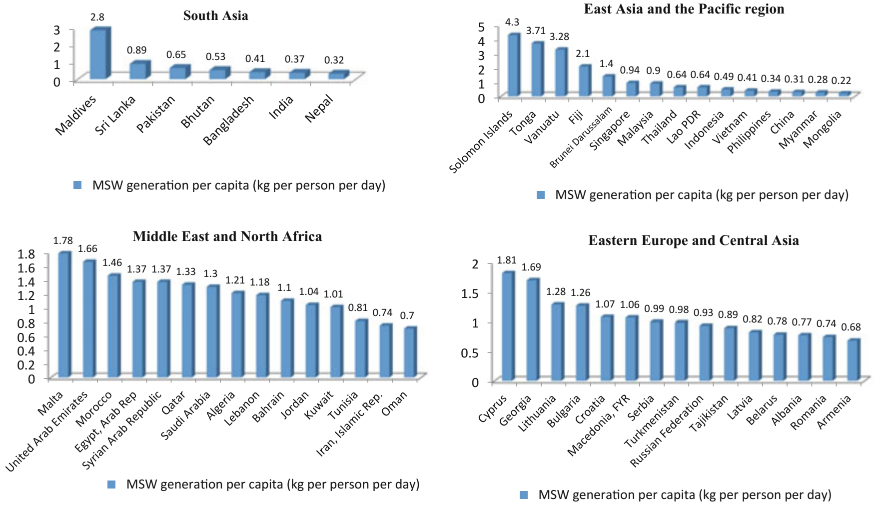


Fig. 1.5 MSWs generation per capita in different regions in Asia (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

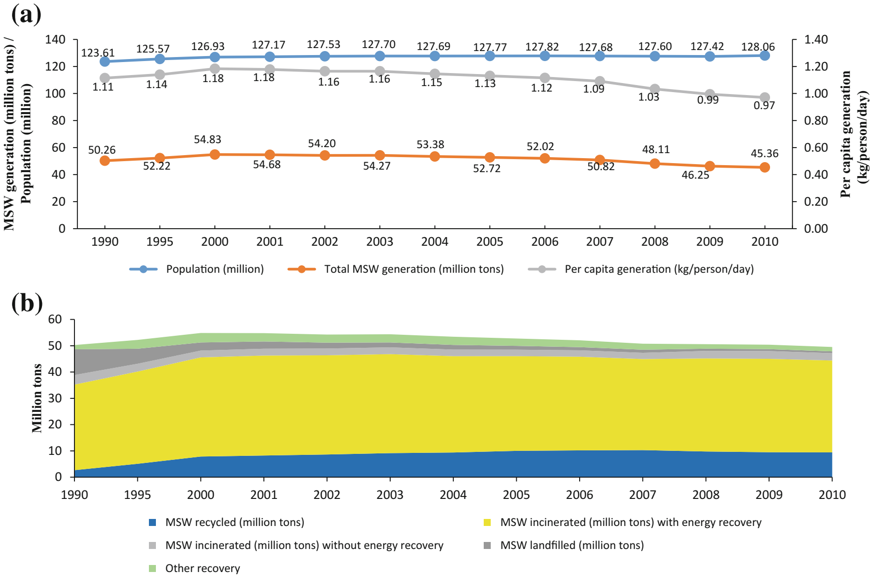


Fig. 1.6 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in Japan (1990–2010). **b** Changes in the contribution of different MSWs treatment options in Japan (1990–2010) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

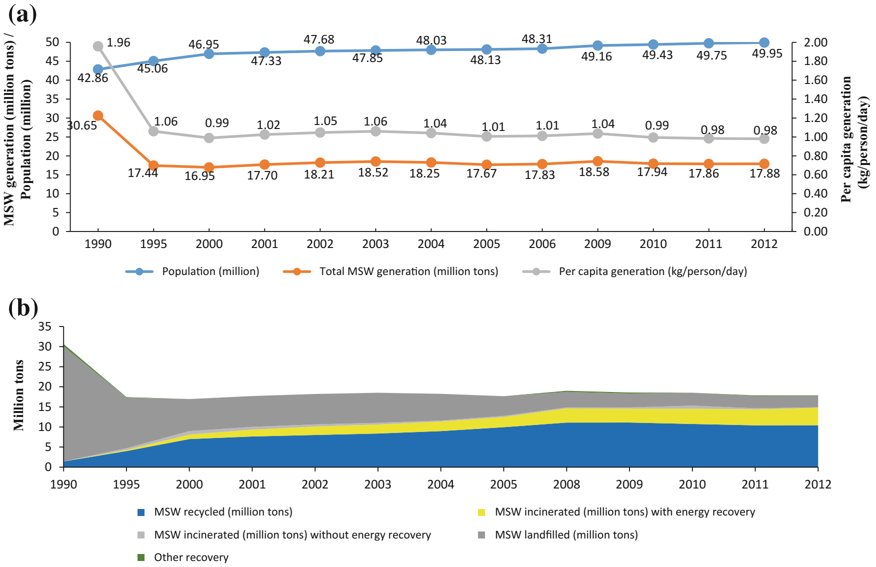


Fig. 1.7 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in South Korea (1990–2012). **b** Changes in the contribution of different MSWs treatment options in South Korea (1990–2012) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

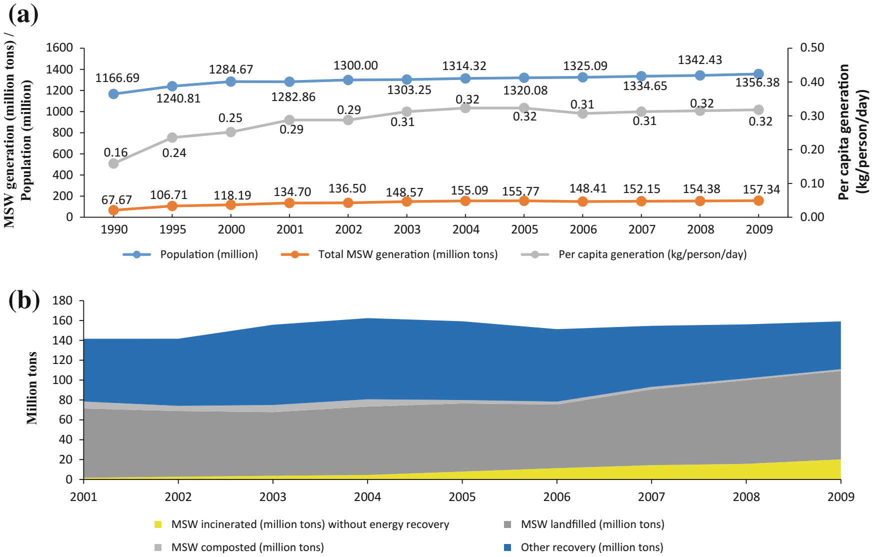


Fig. 1.8 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in China (1990–2009). **b** Changes in the contribution of different MSWs treatment options in China (2001–2009) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

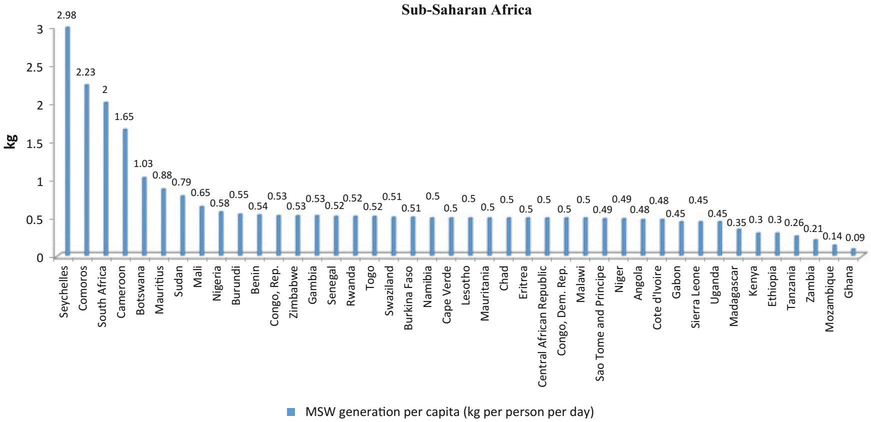


Fig. 1.9 MSWs generation per capita in the Sub-Saharan Africa (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

1.2 Waste Management Strategies

Generally, MSW technologies are divided into two main categories, namely, mechanical and biological treatment, and thermal treatment. Each one of them is also classified into some subcategories as presented in Fig. 1.12.

1.2.1 Materials Recovery Facility (MRF)

MRF, as a critical and vital step in MSWM strategies, consists of three main stages of separation, processing, and storing, aimed at maximizing the quantity of the processed recyclables. It also targets consistent production of clean products from heterogeneous materials containing some levels of contamination with the highest possible revenue in the market. From environmental point of view, material recovery from waste within such contexts substantially offsets the environmental burdens attributed with resource extraction. Based on a study, it is estimated that every t of MSW is responsible for the extraction of about 71 t of upstream materials (Zaman 2016). MRF separates and processes the accepted materials through different operational units and, at the end, stores them as raw materials for remanufacturing and reprocessing in the future (Dubanowitz 2000; Kessler Consulting Inc 2009). In fact, it is the primary systematic and technological step in a particular MSWM strategy and can be considered as the feed supplier of the other waste management systems, e.g., incinerator. Figure 1.13 illustrates the sequence of developing an MRF facility for separating MSW as feedstock.

The choice between manual and mechanical separation techniques is an important issue in the operation of such facilities. With regard to the high labour

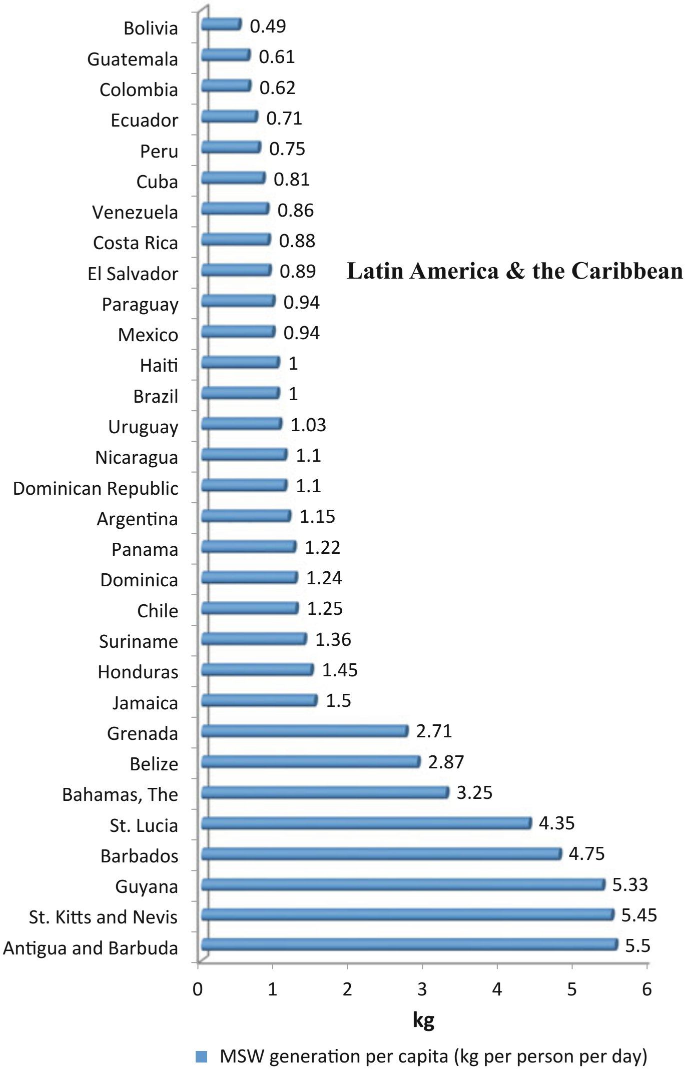


Fig. 1.10 MSWs generation per capita in LAC region (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

costs, the amount of rejected materials, processing rates, adjustability and flexibility to new waste streams, the level of health and safety risks, and separating difficult-to-detect materials (e.g. PVC and PET), automated processing is a much more cost effective choice. However, given the potential of manual sorting in producing higher quality material recovery, automated sorting is usually accompanied with manual sorting in some units. The types of entering materials, the final quality, the inputs and outputs of each subsystem, and the distinguishing

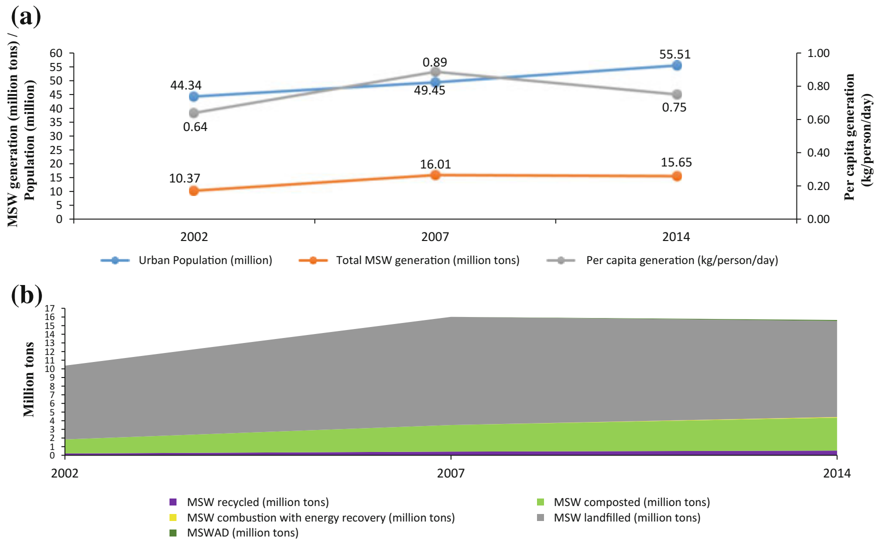


Fig. 1.11 **a** Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in Iran (2002–2014). **b** Changes in the contribution of different MSWs treatment options in Iran (2002–2014) (Rajaeifar et al. 2017). With permission from Elsevier. Copyright © 2017

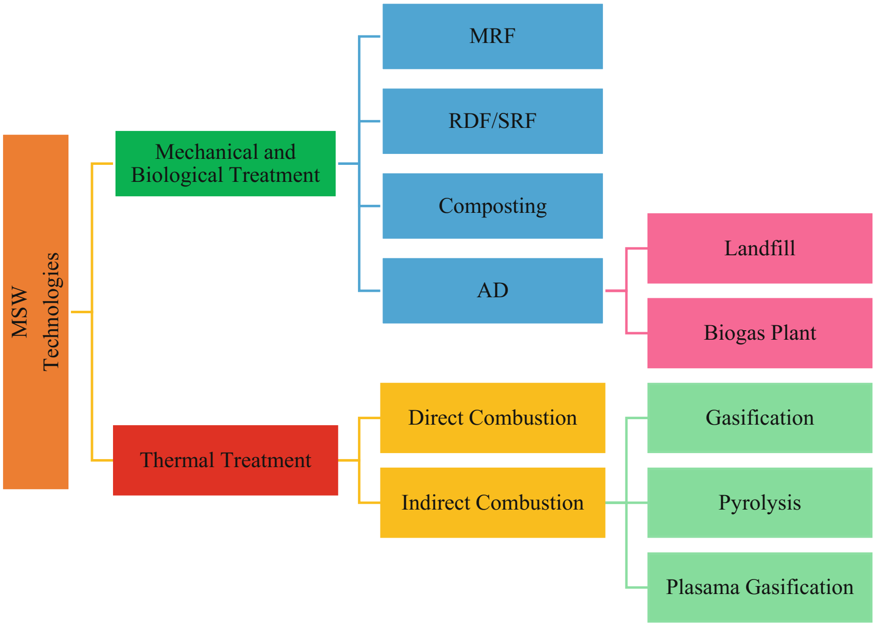


Fig. 1.12 MSW technologies

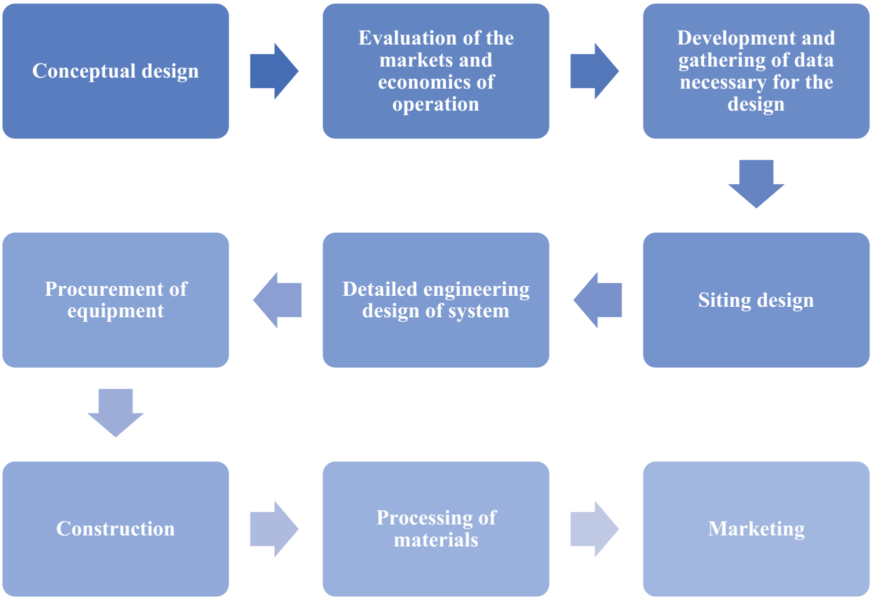
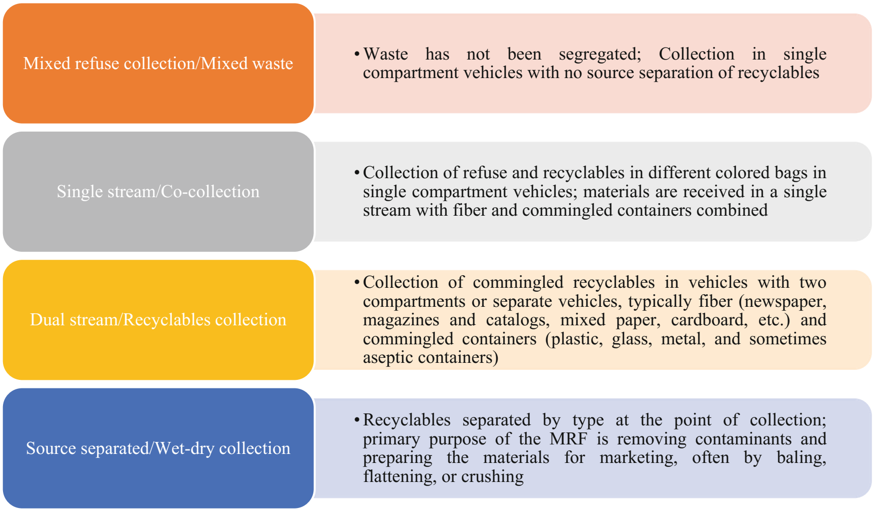


Fig. 1.13 The sequence of developing an MRF facility for MSW as feedstock adopted from Dubanowitz and Themelis (2000)

characteristics of the desired products are the major considerations before designing such unit operations. Overall, an automated MRF may consists of many unit operations with each equipped with various high-tech equipment. These equipment can be any of the followings: (1) Conveyor System; (2) Ferrous Metals Separation; (3) Screening; (4) Air Classification; (5) Non-ferrous Metal Separation; (6) "Detect and Route" Systems, which itself consists of Glass Separation, Plastic Separation, and Paper and Carton Separation; (7) Size Reduction; as well as (8) Compactors and Balers (Dubanowitz 2000).

As an influential factor in designing MRFs, the condition of the input materials will significantly affect the configuration of the processing line. This means that the inflow materials' condition, or the manner by which wastes are collected, will determine the costs and resource utilization of the MRF, as well as its building layout and equipment. In general, MSW can be collected and introduced in four different ways as presented in Fig. 1.14.

Among the critical considerations in developing an MRF unit is to conduct a preliminary investigation on the current recycled materials market and the financial status in a region of interest. This means that a basic requirement for planning new facilities, or for evaluating existing ones, is the simulation of their technical and economic performance (Cimpan et al. 2016). A well-designed MRF unit can cut the municipality's expenses to an acceptable extent by separating the wastes in one stage. Based on a report, the city of Los Angeles faced a 140% increase in the amount of collected waste due to the shift from two-stream to single-stream



Mixed refuse collection/Mixed waste

- Waste has not been segregated; Collection in single compartment vehicles with no source separation of recyclables

Single stream/Co-collection

- Collection of refuse and recyclables in different colored bags in single compartment vehicles; materials are received in a single stream with fiber and commingled containers combined

Dual stream/Recyclables collection

- Collection of commingled recyclables in vehicles with two compartments or separate vehicles, typically fiber (newspaper, magazines and catalogs, mixed paper, cardboard, etc.) and commingled containers (plastic, glass, metal, and sometimes aseptic containers)

Source separated/Wet-dry collection

- Recyclables separated by type at the point of collection; primary purpose of the MRF is removing contaminants and preparing the materials for marketing, often by baling, flattening, or crushing

Fig. 1.14 Four different ways of MSW collection before entering MRF adopted from Dubanowitz and Themelis (2000), Kessler Consulting Inc (2009)

collection scheme in which a highly automated MRF was used. This was followed by a 25% reduction in the collection expenses. In general, by increasing the level of automation, higher speed of operation, lower costs, and higher quality of recovery could be achieved (Dubanowitz 2000).

The extent to which each country recycles its generated wastes depends on various factors including legislations, availability of finance, technological availability, cultural habit-building practices, etc. Among the top 10 recycling countries around the world, the highest rate of recycling belongs to Austria, where 63% of all waste is diverted from landfills. The other following 8 countries are Germany with 62%, Taiwan with 60%, Singapore with 59%, Belgium with 58%, South Korea with 49%, United Kingdom with 39%, Italy with 36%, and France with 35%. The last country is the United States of America which, in the year 2014, produced about 25% of the world's generated waste while only recycled 34% of this huge quantity of wastes (World Bank 2010; Aid 2015; General Kinematics 2016). From another point of view, the higher the landfill tipping fees, the higher the chance of recycling becoming economically feasible as a waste management practice. For instance, between 1985 and 1992, the national average landfill tipping fee increased by more than 500% in the northeaster region of the United States. This substantial increase together with an increased reliance on costly and contentious waste exportation made recycling as an economical and proven approach for waste management (Dubanowitz 2000). Nowadays, the use of systems featuring a variety of equipment, from screens, to optical sorters, to cutting-edge electrical solutions are the state-of-the-art technologies to meet the highest quality standards. It should also be noted that an MRF facility can be designed extremely automated, but, as mentioned earlier, the higher the automation, the higher the capital cost as well (Advancedmrf 2017; CPG Group 2017).

1.2.2 Refuse-Derived Fuel (RDF)—Solid Recovery Fuel (SRF)

In order to mitigate the devastating consequences of landfilling along with an efficient utilization of the energy contained in waste, RDF and, its new version, i.e., SRF, have been introduced as strategy in MSWM scenarios to be used in power plants, cement kilns, and other combustion plants. The creation of RDF dates back to the time of the energy crisis in the 1970s. In spite of the different definitions offered for RDF and SRF across different countries, based on Italian decrees (Ragazzi and Rada 2012), the RDF and SRF are defined as follows (Rotter 2011; Ragazzi and Rada 2012):

> RDF is fuel derived from municipal solid waste through treatments aimed to the elimination of substances hazardous for combustion and to guarantee an adequate lower heating value (LHV), and to comply with the technical norms for its characterization.
>
> SRF is the solid fuel prepared (means processed, homogenized and up-graded to a quality that can be traded amongst producers and users) from non- hazardous waste to be utilized for energy recovery in incineration or co- incineration plants and meeting the classification and specification requirements laid down in CEN/TS 15359.

In fact, the two fuels are termed based on their characteristics. Nowadays, the terminology RDF is known as unspecified waste after a basic processing to increase the calorific value and usually refers to the segregated, high calorific fraction of MSW, commercial or industrial wastes (Rotter 2011). SRF, as newer terminology, refers to non-hazardous waste, utilized for energy recovery, and is more homogeneous as well as less contaminated than the generic RDF (Garg et al. 2007). Figure 1.15 shows different unit operations in an RDF production plant.

Based on a classification by the American Society for Testing and Materials (ASTM), RDF is divided into seven categories, depending on the type of processing and not based on chemical or physical parameters (Rotter 2011). As an important advantage, RDF/SRF can be shipped, under transfrontier shipment (TFS) regulations, across countries as an energy carrier (Clarity Environmental 2017). This type of energy carrier can be co-combusted in cement kilns plants, in which up to 40% of their firing thermal capacity can be provided using high calorific waste fuels, co-combusted in coal fired boilers (lignite or hard coal), or mono-combusted in RDF-fired boilers (grate firing or fluidized bed technology) with the aim of district heating or steam and electricity for industries (Rotter 2011).

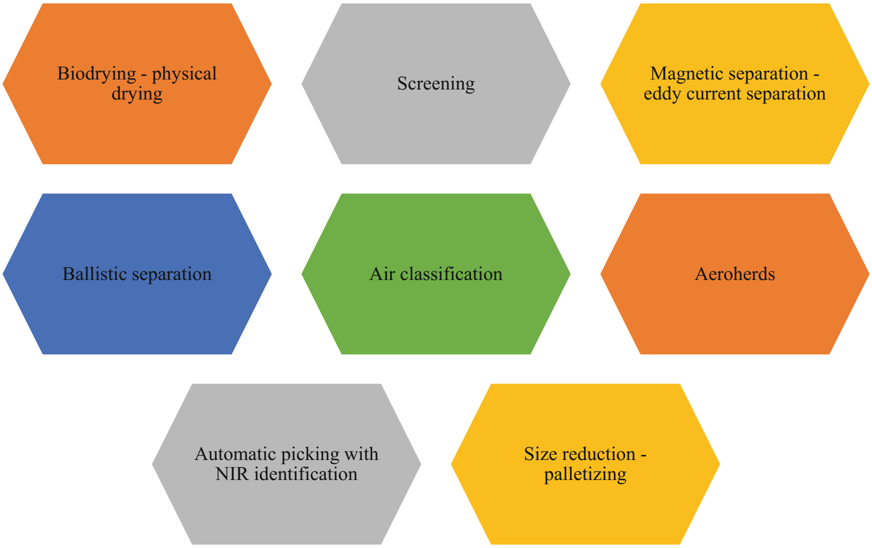


Fig. 1.15 Various unit operations in RDF production. Adopted from Christensen (2011)

1.2.3 Landfill

Landfilling, i.e., dedicated use of land for disposing waste in an engineered facility, is still the predominant and widespread concept for the MSWM of the waste generated by about 7.5 billion of the global population. This prevalence is mainly due to its being the most cost-efficient method of waste disposal, it does not mean that this technology is associated with low environmental risks though. In fact, water, soil, and particularly air are prone to be contaminated by the deposition of wastes in landfills. More to this, a great deal of concern is about its long-term negative impacts on the future generations, since the decomposition of organic materials (OM) under anaerobic conditions takes place at a low rate. Therefore, an appropriate design, considering the type of waste that has to be landfilled together with various standards, conditions, and regulations, should be implemented (Christensen 2011; Pawłowska 2014; Richards and Taherzadeh 2016).

It would be wise to implement a resource recovery facility, moving toward a more sustainable society, even if landfilling is the only option (Richards and Taherzadeh 2016). By constructing and implementing an engineered collection system along with the utilization of complex bio-chemical conversion processes (including different phases like Initial Adjustment, Transition Phase, Acid Phase, Methane Fermentation, and Maturation Phase), biogas, as an energy carrier, can also be harvested from landfills directly (World Energy Council 2013). Typical major biogas composition in a landfill site is: CH_4: 47.7; H_2O: 20; H_2S: 2.4; and CO_2: 29.6 (Fehr 2010).

Technologies related to landfilling can be categorized into five distinct types, namely, aerobic, semi-aerobic, hybrid, anaerobic, and landfill as deposit of inert waste. More in-detail explanations about each type of landfilling technology, as an approach to minimize the impacts of landfills on the atmosphere and the environment, can be found in Pawłowska (2014). The aim of the complex system of interrelated components and sub-systems of a landfill is to break down and stabilize disposed wastes over a long period of time. Each of these types of landfills can to some extent address different concerns including disease vectors such as flies, mosquitoes, cockroaches, rats, and other pests, as well as groundwater contamination because of leachate production (Dhamija 2006).

Each of the above landfill types may be considered for a region based on its local conditions; however, among them, the semi-aerobic bioreactor (known as Fukuoka method due to its first implementation in the city of Fukuoka in Japan in 1975) is one of the best choices in designing a landfill with low capital and operational costs, while meeting the regulations and expectations. Low degree of technical demand, machines, devices, and ease of operation and maintenance, decrease in the load of waste water contamination by quick drainage of waste water, contribution to the prevention of Global Warming by control of the discharge of methane gas, early stabilization of landfill ground by promoting waste bio-degradation, wider alternatives of material for construction, and lower cost of construction are the other advantageous of Fukuoka landfilling method (Global Environment Center Foundation 2006; Fukuoka Municipal Government 2010).

Nowadays, developing sustainable techniques and technologies to enhance the stabilization of landfills and to harvest energy from landfills are the major objectives of modern landfilling. For instance, landfill reclamation, a treatment operation and perhaps the most sustainable manner in operating a landfill, has been utilized in a few regions. Many other practices may also be applied in landfilling to achieved the aforementioned objectives (Krook et al. 2012; Ritzkowski and Stegmann 2012; Pawłowska 2014; Townsend et al. 2015; Wolfsberger et al. 2016).

1.2.4 Compost

Composting, the biological decomposition of organic matter under aerobic conditions, is an excellent and valuable waste management technology. In recent years, composting of MSW has received much attention as a way of ameliorating the soil's physicochemical properties and improving the biological responses of cultivated lands. Eradicating several food-borne diseases (caused by bacteria, viruses, and parasites), providing nutrients for crop production, avoiding methane production and its release to the atmosphere, conserving moisture in soil, improving soil conditions for better crop growth, producing a product that can improve plant growth, reducing runoff and erosion, as well as minimizing landfilling or incineration of waste are the other common benefits of composting practiced by both with the developing and developed countries (Epstein 2011; Srivastava et al. 2016).

There are eight influential factors in composting operation viz. turning frequency, temperature, C/N ratio, moisture content, electrical conductivity, aeration, pH, and particle size. More to this, oxygen and moisture, as the two prominent operational parameters, together with temperature and nutrients, especially carbon and nitrogen, affect the rate of decomposition of the organic matter during composting and are required to be maintained at an optimum level. It has been proved that these operational factors are interconnected. For instance, turning frequency affects total nitrogen, pH, moisture content, carbon to nitrogen (C/N) ratio, dry matter, total carbon, and temperature of composting piles, and, as another example, the higher the O_2 concentration, the lower the concentration of organic acids in the compost leading to a rapid decomposition of the acids. More in-detail information can be found in numerous literatures (Epstein 2011; Onwosi et al. 2017).

Various technologies have been introduced for composting organic materials. There may also be different classifications, among which the concise generic classification tabulated in Table 1.2 is widely approved. In order to choose the most appropriate system, many factors should be considered, that is, economics and cost,

Table 1.2 The generic classification of composting technologies and systems. Adopted from Epstein (2011)

Static Systems	*Passively Aerated Windrows*	Relies on convective air to provide oxygen and to achieve favorable temperatures and stabilization; uses perforated pipes open to the atmosphere; feedstock with a bulking agent is piled over the pipes; not an approved U.S. Environmental Protection Agency (USEPA) method for pathogen reduction for the use of sewage sludge or biosolids; used as a low-cost technology by farmers for composting animal wastes
	Forced Aeration —Static Pile	Originally developed using negative air, i.e., suction, leading to reduction in odors by sucking the air through pipes (negative aeration) and filtering the air into a biofilter; currently utilized using positive air, i.e., forcing the air through the pile, leading to head loss reduction and unrequired external biofilter as the advantages; availability of numerous configuration, e.g., totally open/enclosed
	Bin/Container/ Bag/Tunnel	Principally applied to small facilities; can be very effective in odor control; usually ventilated and are horizontal; different in the way these are loaded, unloaded, and ventilated; mostly used for relatively low volumes of feedstock and where the location is sensitive to odors; require a mixing and final preparation of the product through screening or other techniques
	Silo/Vertical Reactors	Principal problems were excessive compaction, poor aeration, and difficulty in extracting the material; currently are not being built and many have been discontinued

(continued)

Table 1.2 (continued)

Turned/ Agitated Systems	*Windrow*	Essentially operated outdoors; uses turning system where the machine straddles the windrow and agitates the material; attributed with a great deal of emissions; odors can be a significant problem; major advantages are large volume of material it can handle and excellent quality of mixing and pulverizing the material; varies in width and height depending on the equipment used; windrows are 1.5–2.7 m (5–9 feet) high and 2.7–6.1 m (9–20 feet) wide with spaces considered in between for the turning machine; aeration is provided primarily through convective airflow; turning not only provides mixing, but also improves porosity and breaks up the particles
	Drum/Kiln	Have been used in many facilities in the Europe, but to a very limited extent in the United States; uses elongated drums to mix the solid waste and biosolids; mixture is then composted in an agitated bin system; limited temperatures are obtained as well as limited biological degradation of the feedstock; retention time in the drum varies with the technology; stabilization of the compost may be needed; the drum does not lead to complete composting; retention in drums is usually from 24 h to 7 d, depending on manufacturer specifications; additional composting and curing are usually done in aerated bays or windrows
	Agitated Bed	Numerous variations of the agitated bed; horizontal systems using turning machines, paddles, or other turning devices; principally used in the United States for composting biosolids; all are enclosed

location, amount of materials to be handled, type of feedstock, as well as state, country, or local regulations (Epstein 2011).

Sewage sludge, biosolids, septage or night soil, manure, animal mortalities, food waste, yard waste, MSW, industrial wastes, and military wastes are the different types of feedstocks in composting. Numerous factors such as feedstock source and ratio used, toxic compounds, the composting design, maturation length, and procedure adopted during the process of composting are the determinative factors in the quality of the compost obtained from MSW (Epstein 2011; Srivastava et al. 2016).

It has been observed that odours or gas emissions, lack of uniformity of compost maturity index, leachate generation, and subsequent concerns about potential diseases, bioaerosols, or impacts of chemicals, raised by citizens, are the most important operational obstacles facing composting operations. With this in mind, the major focus has been shifted from the utilization of compost and its importance in horticulture, erosion control, plant pathology management, and other uses to emissions and their control over the past decades. In another word, composting has evolved into a more sophisticated technology with environmental and public health aspects as the main focus. More specifically, odour management, volatile organic compounds (VOCs) reduction, and bioaerosols management are the technological points with greater emphasis (Epstein 2011).

Currently, state-of-the-art bioreactor (biological air treatment) design, new indices for determining compost maturity, developing the means to harness heat from composting process as bioenergy, modelling of gas compounds removal and microbial structure analysis, developing technologies related to odour treatment/control (use of additives), use of inexpensive pre-treatment processes and genetically modified strains as microbial inoculum, as well as moving toward more cost-effective and efficient processes are the cutting-edge research fields and developments (Onwosi et al. 2017).

1.2.5 Biogas

Biogas, the product of the complex biochemical decomposition of organic materials, mainly consisting of 60–70% methane (CH_4), 30–40% carbon dioxide (CO_2), together with the other gases, i.e., nitrogen (N_2), hydrogen (H_2), hydrogen sulphide (H_2S), ammonia (NH_3), as well as water vapour. It is produced through an AD process by consortia of bacteria and archaea. In another word, it is a complex microbial process occurring naturally in oxygen-free environments and is considered as one of the most efficient methods for conversion of biomass to CH_4. The process may be divided into four steps viz. hydrolysis, acidogenesis, acetogenesis, and methanogenesis. A wide range of materials including agricultural wastes, MSW, food waste, industrial waste and wastewater, as well as crops may be considered as feedstock for the AD process (Rapport et al. 2008, 2012; Ullah Khan et al. 2017).

Each of the above materials has their own potentials for biogas, or more specifically biomethane, production. Volatile solids (VS) content, biological (biochemical) oxygen demand (BOD), chemical oxygen demand (COD), C/N ratio, and presence of inhibitory substances are among the most important feedstock parameters to be considered. Not only do the feedstock characteristics affect the performance of AD processes, but also do many factors including reactor design and operational conditions, either by process enhancement or inhibition. Biogas production potential should also be investigated through one or some of the various methods as a crucial step in designing a biogas plant (Jingura and Kamusoko 2017). These methods are broadly divided into two categories namely experimental and theoretical methods. More in-detail information regarding the subcategories of the methods used can be found in Table 1.3.

Many design options have been proposed for AD systems including wet, dry, thermophilic, mesophilic, batch, continuous, single-stage, and multi-stage configurations. However, the process itself is divided into two general categories viz. wet and dry, or, in another word, the AD process is applied to feedstocks ranging from highly liquefied to the ones with high solid contents (e.g., MSW). Likewise, the AD system can also be divided into batch or continuous and single-stage process or

Table 1.3 Different methods for determination of biomethane potential of feedstock*

Method type			Description	Advantages	Disadvantages
Experimental method	*BMP Test (Biochemical Methane Potential)*	Conventional	• Mixing an organic feedstock with an inoculum in distinct operational conditions as the general principle • Physically quantify the gas produced by manometric or volumetric method • The biogas composition is determined by GC • Various technical approaches and experimental sets, e.g., Specific Methanogenic Activities (SMA) test, Anaerobic Biogasification Potential (ABP) test, are used • Influential parameters temperature; pH; inoculum; substrate/inoculum ratio (S/I); particle size; stirring intensity; headspace flushing	• Easy to use • Inexpensive • Repeatable	• Time wasting • Resource consuming
		Automatic	• Automatic Methane Potential Test System (AMPTS) was developed by the Bioprocess Control Sweden Company • Utilizes the basic principle of the conventional BMP test • Methane production is directly measured on-line by means of liquid displacement and buoyancy method • A new version developed is called Biogas Activity Monitoring (BAM) • Influential parameters temperature; pH; inoculum; substrate/inoculum ratio (S/I); particle size; stirring intensity; headspace flushing	• Uses less labour • The equipment is inexpensive • Provides high quality and adequate quantity of data	• Require sound systems

(continued)

Table 1.3 (continued)

	Spectroscopy	The Envital Kit	• Recently introduced as a rapid assay based on fluorescence • The Envital® kit is capable of estimating anaerobic biodegradability of sewage sludge in early stages of development • Results are ready in 48 h • Uses a fluorescent redox indicator	• Rapid • High-through put characterisation of more than 32 samples simultaneously in 48 h • Quickly answers operational requests	• Still in early stages of development • Needs more time for validation
		Near-infrared	• Useful tool for quantitative prediction of compounds in pharmaceutical, food and agricultural industries • Recently emerged as a simple and cheap alternative to several laboratory methods for the quantification of BMP • Is used in conjunction with sophisticated chemometrics	• Rapid • Chemical-free • Easy to use (once calibrations have been developed) • Non-destructive	• Machines are too expensive • Calibration is less accurate than wet chemistry • Small calibration sizes can lead to overconfidence • Measurements outside the range of calibration samples are invalid
		Fourier Transform Mid-infrared	• Suitable for in-line determination of volatile fatty acids (VFA), alkalinity, COD, and TOC • Requires the interpretation of the obtained spectra which is more difficult with NIR spectroscopy due to overlapping overtones and combination bands • FTIR-photoacoustic spectroscopy (FTIR-PAS) is the modified version • Creates a thermal wave from the vibration of molecules as a result of the infrared and the sample interface	• Relatively fast and simple to use • Sensitive and requires small amount of sample • Non-destructive method • Universal method: the instrument and software readily available and can be utilised for routine analysis • Multiple sample analysis: can test samples in the form of liquid, gas, powder, solid or film • Relatively cheap as compared with many other methods • Provides qualitative as well as quantitative data	• A single sample requires background scans and many scans due to variations in the spectra caused by environmental factors surrounding the FT-IR spectrophotometer • May require standardization, extensive data collection and skills in chemometric analysis of spectra

(continued)

Table 1.3 (continued)

Theoretical method	*Chemical composition*	• Applicable in cases where elemental composition of the substrate is unknown • Can be done economically within a short period of time • A more rapid and cheaper method than the BMP test	• Rapid • Cheap • Useful in cases where access to • Laboratory facilities is restricted	• The accuracy of each method presumes complete degradation of OM, yet the actual digestibility is usually 27-76% • The BMP is over-estimated • Several inhibitions may occur during the digestion process, and are not considered in these methods • Requires a lot of measurements which time consuming and costly
	Chemical oxygen demand	• COD indirectly measures the amount of organic matter • Can be applied to estimate the CH_4 yield of biomass • Based on the assumption that 1 mol of methane requires 2 mol of oxygen to oxidize carbon to carbon-dioxide and water		
	Elemental composition	• Applied to calculate theoretical BMP • Consists of different formulas, e.g., the Buswell formula—based on the assumption that OM (e.g., $C_nH_aO_b$) is completely degraded to CH_4 and CO_2, the modified Dulong formula—based on energy value of the feedstock that is estimated from its elemental composition		

**Source* Jingura and Kamusoko (2017)

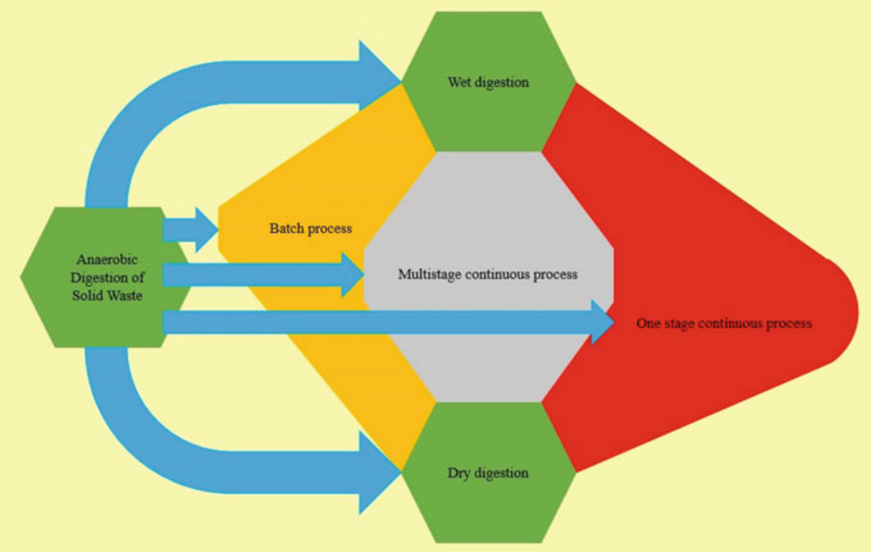


Fig. 1.16 Various AD methods adopted from Richards and Taherzadeh (2016)

two/multistage processes (Richards and Taherzadeh 2016; Rapport et al. 2012). There are numerous companies around the world (European at the top) providing technologies, equipment, and services to the biogas sector. An up-to-date list of these active companies can be found in the report published by Energietechnik et al. (2016). Figure 1.16 presents a holistic overview of the current biogas production methods in the world.

1.2.6 Combustion; Direct and Indirect

Incineration, waste combustion with the goal of disposing waste fractions that cannot be recycled or reused, has been practiced and developed over more than a hundred years. The main objective has evolved from reducing waste volumes and hygienic problems to state-of-the-art waste-to-energy plants accompanied by extensive processes and emission control systems. A key factor in determining the feasibility of generating energy from waste is its heating value, which is expressed as lower and higher heating values (Christensen 2011; Richards and Taherzadeh 2016). A thorough review upon various methods in determining the heating values can be found in Christensen 2011. Table 1.4 shows different routes of waste combustion with their in-detail specifications.

Additionally, an important issue in case of incineration is the public perception about the technologies used which has to be taken into account. This perception is significantly different among various countries around the world, i.e., people in

Table 1.4 A general overview of thermal treatments, i.e., direct and indirect combustion technologies*

Thermal Treatment	Reactor/process type	Description	Advantages	Disadvantages
Direct combustion	Stoker/Grate Furnace	• Conventional mass burn incinerator • Many different designs • Keeps a fuel bed on top of a grate while letting primary air pass through the grate from beneath • Appropriate for waste by use of a sloping reciprocating grate • Typically, a grate can consist of 2–4 modules in a series and 1–2 modules in parallel • 1 MW/m^2 is the usual order of specific heat rate released from the grate; normally, about 60% of the total combustion air is supplied as primary air through the grate • Accompanied by Flue Gas–Cleaning System including particle precipitation, CO control, scrubbers for HCl and SO_2 removal, NO_x removal		–
	Fluidized Bed (FB)	• Consists of a bed of sand (or similar inert material) at the bottom of the combustion chamber • Two main categories: (1) bubbling fluidized bed (or simply fluidized bed)—in the order of 20 MWth is the preferred choice for moderately sized boilers, (2) circulating fluidized bed • No moving parts and, therefore, lower investment cost • Higher running operational cost due to the need for fresh sand and a more homogeneously crushed fuel • Accompanied by Flue Gas–Cleaning System including particle precipitation, CO control, scrubbers for HCl and SO_2 removal, NO_x removal	–	–
	Rotary Kiln	• Consists of a layered burning of the waste in a rotating cylinder • The energy efficiency may not exceed 80% • The possibility of being joined with a moving grate (moving grate as the ignition part and the rotary kiln as the burning out section) • More maintenance is required	–	–

(continued)

Table 1.4 (continued)

			• Rarely used for new MSW incineration plants with high heating value wastes • Common for burning waste with special characteristics, e.g. hazardous/chemical waste where confinement of the waste matters or for low heating value waste such as animal waste/carcasses; may be utilized in gasification • Accompanied by Flue Gas–Cleaning System including particle precipitation, CO control, scrubbers for HCl and SO_2 removal, NO_x removal		
Indirect combustion	*Gasification*	Fixed Beds (Downdraft, Updraft, and Slagging Fixed Beds)	• Generally used for lower throughputs resulting from difficulties in having a large diameter without causing the gases to be channeled • Based on the direction of the gas flow mostly consists of two kinds: updraft (in the opposite direction to the solid material) or downdraft (in the same direction to the solid material) • Downdraft system is more complex, requires more control, leads to high quality produced gas, and is devoid of damaging the gas turbine • Updraft gasifier handles a greater variation in the feedstock quality well (e.g., heat content and moisture content), produces a gas with rather high amounts of tars, as a stand-alone unit has a high energy efficiency • Slagging fixed beds operate at high temperatures for inorganic material—the material is melted and forms a molten solution (is often quenched before further treatment)—as a disadvantage, lime and coke are required to be added to the gasifier not only to control the viscosity of the smelt but also to ensure full reduction conditions in the lower section while keeping the temperature sufficiently high—Nippon Steel and JFE are the two main suppliers	• Recovering chemical energy in the waste as hydrogen and/or other chemical feedstocks rather than converting this energy into hot flue gases • Generally better energy efficiency; lower possibility of corrosion • Less need for flue gas cleaning: better quality and smaller volumes of flue gas • Influential in CO_2 capture • Potentially lower emissions of dioxins • Better quality of solid residues • Utilized in high-temperature processes • Low fuel load in gasification units; potentially lower costs	• Relatively homogeneous fuels are required • Troubles with slagging, tar production, and contaminants in the produced gas are common • Complicated to be controlled (despite the theoretical possibility) • Numerous waste related pyrolysis and gasification technologies only applicable to specific fuel types in small scale • Unable to compete with modern waste regarding overall energy conversion efficiencies
		Fluidized Beds (Bubbling and Circulating)	• Having a rapid and effective heat and mass transfer within them that distributes the fuel and increases mixing • The fuel must be pretreated • A bed material (usually sand) is required		

(continued)

Table 1.4 (continued)

			• Depending on the velocity of the gas divided into circulating and bubbling • Ebrara, Kabelco, and Hitachi Zosen are suppliers of bubbling fluidized bed gasifiers for treating waste		
	Plasma	Plasma Gasification	• It is generated at temperatures exceeding 2000 °C and is generally created by an electric arc • Dissociation of gas molecules starts at about 2000 °C and subsequently at temperatures above 3000 °C, they become ionized by lose of electrons • All tars will be eliminated • Alter NRG, Gasplasma® (Advanced Plasma Power, Swindon, UK), Plasco (Plasco Energy Group, Kanata, ON, Canada), and CHO Power (Europlasma, Oudenaarde, Belgium) are companies currently working with plasma in small-scale waste gasifiers (not yet been used commercially on a large scale)		
	Pyrolysis	Slow Pyrolysis	• Low heating rate of the solid material • The residence time of the solids is in the order of hours • Mild treatment and low entrainment of material into the gas phase are guaranteed • Low temperature (around 500 °C), thereby requiring a longer residence time and giving a solid char with a higher amount of oxygen and hydrogen • Lower energy demand • Less violent reaction during gas devolatilization • More carbon-rich char and less tars in the gas phase result by applying higher temperatures (above 700 °C)		
		Fast (Flash) Pyrolysis	• To produce bio-oil at approximately 510 °C with a proper feeding rate • To explore the secondary cracking of tar at longer residence times • Induces the presence of waxy materials in the liquid products • The higher the temperature, the lower the liquid yield • Currently no large-scale plant is in operation		

**Source* Klein (2002), Christensen (2011), Bosmans et al. (2013), Chen et al. (2015), Richards and Taherzadeh (2016) some countries consider incineration plants as a safe and clean waste treatment technology reducing fossil fuel consumptions, while others might think of these plants as major contributors to air pollution, climate change, and public health threats.

Pyrolysis oil and gas, the possibility of recycling the solid materials (i.e., char and metals) after separation are the opportunities offered by pyrolysis. Likewise, production of a clean synthesis gas that can be used in gas turbines or gas engines is the main opportunity offered by gasification. Other advantages include possibly lower emission levels, further reduction in the formation of possible toxic substances (such as dioxins and furans) due the possibility of applying high temperatures and the presence of a high degree of vitrification (slagging), possibility of using the inert produced materials in construction or roads.

On both direct and indirect combustion techniques, research activities aiming at optimizing the processes involved are in progress, especially with a focus on environmental concerns. In case of gasification, it has been used together with ash melting with the goal of achieving very low emissions and increasing the use of solid waste. In the same way, coupling industrial pyrolysis facilities with gasification and combustion stage equipped with gas scrubbing devices are the current state-of-the-art developments (Chen et al. 2015; Panepinto and Zanetti 2017; Richards and Taherzadeh 2016).

1.3 Feasibility Study

Nowadays, MSWM systems consist of various options including materials collection, MRF, composting, combustion, and landfilling, that is, they are highly integrated (Dubanowitz 2000). In order for having an efficient systematic MSWM, a thorough investigation upon various on-going systems, conditions, and policies of the targeted area has to be implemented. This investigation has to cover the collection system (inspection on the overall efficiency of the current system mainly from economical point of view), waste producing sources, demographic and meteorological profiles, social influential parameters, hygienic conditions, water availability (surface and groundwater), electricity distribution and grid accessibility, physical, chemical, and heating value analysis, as well as on-going and future regulations.

More specifically, a given investigation should include an inspection on:

- the collection system to possibly implement new strategies for a more economical system together with lower negative environmental impacts;
- waste producing systems to specify an appropriate fee for every particular producer regarding its type of waste and also targeting illegal producers especially in developing or undeveloped countries;

- demographic and meteorological profiles including immigration rate, precipitation profile, sunny days, wind roses, temperature profile, and the climate for future considerations;
- social influential parameters including acceptability of new technologies among the people or the level of their knowledge about waste management in general for future considerations;
- hygienic conditions including the amount of health-care or hospital waste and the number of centers;
- surface and ground water accessibility for if a particular place is suitable for a particular waste management system;
- electricity distribution and the grid accessibility for selling the possible generated electricity in the future;
- physical, chemical, and heating value analysis of whole generated waste as the most important factor in determining the best scenario;
- on-going and future regulations for the chosen technologies whether or not there is a discrepancy between the regulations and the chosen systems.

In case of MSW standards, there are a few standards, among which ASTMs are more acceptable across countries. Some of these standards are ASTM D4979-12 for physical description screening analysis in waste, D5231-92(2016) for determination of the composition of unprocessed MSW, and D5681-16a for waste and waste management. The complete list of ASTM standards in waste management can be found in ASTM (2017).

In the following subsections, two of the most important must-do investigations, i.e., LCA and financial feasibility, will shortly be discussed.

1.3.1 LCA

Grown to be a major tool to evaluate the environmental performance of products and services, LCA is now utilized for economic analysis of all kinds of activities, from cradle-to-grave, i.e., from resource extraction, manufacturing, transport, wholesale and retail, to use and end-of-life management. Covering approximately all the environmental stressors that contribute to all the problems facing mankind, from resource depletion, climate change, smog formation, acidification, eutrophication, to noise, ecological toxicity, biodiversity loss, and human health (e.g., cancer) as well as non-cancer effects makes this analysis invaluable for decision makers (Hauschild et al. 2018).

Moreover, considering various distinct policies, regulations, and social as well as economic circumstances across countries, LCA is a vital and critical tool to estimate and compare the environmental impacts of waste management strategies (Jeswani and Azapagic 2016). For instance, based on a comparative LCA of five different MSWM scenarios in Iran by Rajaeifar et al (2015), landfilling combined with composting, a conventional but fading MSW management practice in Iran, was the worst scenario; however, the combination of AD with incineration was suggested as the most environmentally-friendly procedure (Rajaeifar et al. 2015).

1.3.2 Financial Feasibility

Financial feasibility, as an important and critical step in accessing the practicality of a proposed project, has to be conducted in order to find an in-detail cash flow in the project. As it is depicted in Fig. 1.17, many factors from two major costs subcategories, that is, investment and operational costs, have to be analysed carefully. In case of conducting the analysis, a few software have been developed, among which COMFAR III EXPERT is among the most promising ones.

In fact, COMFAR III EXPERT (Computer Model for Feasibility Analysis and Reporting) is a tool that has been developed by United Nations Industrial Development Organization (UNIDO), based on the experience, recommendations, comments, and needs of more than 7000 users in 160 countries to solve industrial problems, investment analysis, etc. Since its release, the software has been upgraded yearly to meet the technical developments as well as users' requests (UNIDO 2002).

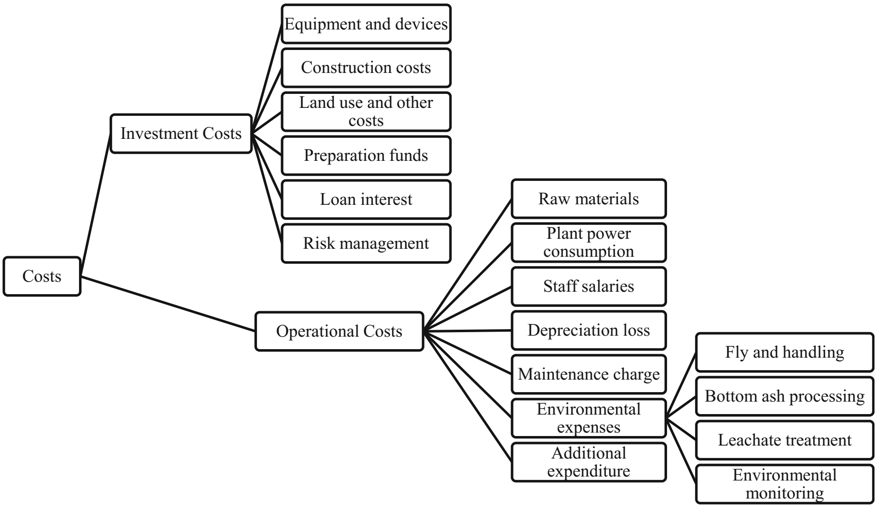


Fig. 1.17 The cost structure of WtE plants (Zhao et al. 2016). With permission from Elsevier. Copyright © 2017

1.4 Conclusions

Over the past century, the term “waste management” has taken a growing level of attention mainly due to the lifestyle changes and swift industrialization process all around the world. From economic and environmental points of view, waste, as a subjective definition, has become a valuable source of various materials, while would be a curse considering especially its negative environmental impacts. In order to have an optimal and efficient management system, building a scenario is a critical step. Within a scenario, various strategies could be applied to the whole system, i.e., a better and optimized collection system along with an efficient WtE system. WtE systems must be chosen by carrying out a thorough investigation of the local conditions of a targeted region. A system with a particular technology may be suitable for a region, while it may lead to a disaster for another region. Ultimately, the scenario can help a wide range of audience, from governments and companies to non-governmental organizations such as environmental protection agencies, to set their long-term objectives logically.

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