Chapter

Introductory Chapter: Municipal Solid Waste

Hosam M. Saleh and Martin Koller

1. Introduction

Rapid growth of the global population, permanently increasing life standards, and vast technological advancement are continually increasing the variety and amount of solid waste.

Generation of municipal solid waste, together with the high organic share present in solid waste and its often incorrect discarding, results in extensive ecological pollution, mainly based on the emission of gases that contribute to the greenhouse effect, such as methane (CH_4) and carbon dioxide (CO_2). Because of this environmental threat, municipal authorities are currently urged to implement techno-economic and political solutions of higher efficiency to manage the growing quantities of municipal solid waste [1].

The lion's share of municipal (mainly urban) solid waste consists of biodegradable matter, which plays a substantial role in greenhouse gas emissions in today's cities all around the globe. According to the present state of knowledge, integrated solid waste management is the strategy of choice to manage this issue; such strategies, however, require improvement in order to handle the growing organic fractions of municipal solid discards. If accomplished in a smart manner, this can on the one hand contribute to the aspired reduction of greenhouse gas emissions, and, on the other hand, even potentially generate economic benefits. Hence, systems for sustainable management of municipal solid waste are auspicious and attractive objects of study to assess current consumption behavior in different global regions and to protect the natural environment.

Generally, municipal solid waste gets disposed of in dumps and landfills as the most simple, convenient, inexpensive, and technologically less advanced method. Organic fractions as the major component of municipal solid waste undergo biodegradation under the anaerobic conditions prevailing in landfills, which consequently releases greenhouse gases as mentioned above [2].

Reduction or complete abolition of environmental contamination becomes increasingly important, which intensifies the global efforts dedicated to develop novel strategies for gradually reducing the quantities of the biodegradable municipal solid wastes in landfills. The process toward reduction of organic pollution involves (i) source separated collection of organic fraction of municipal solid waste, which undergo compost production, (ii) organic waste incineration for energy production, and (iii) mechanical/biological processing to get a compostable material [3].

This introduction chapter makes the reader familiar with the principles of municipal solid waste management, encompassing landfilling and recycling technologies; moreover, the composition of different types of municipal solid waste will be introduced. Based on this, the most feasible, promising, and realistic scenarios for municipal solid waste management are presented in order to provide a solid scientific background of these processes implemented or in development, and the factors needed to assess the sustainability of these processes in a critical and straightforward fashion by using innovative sustainable assessment tools [4].

2. Emergence and generation of municipal solid waste

"Municipal solid waste" is commonly understood as the waste accruing in a municipality. Most of this solid waste is generated without any segregation, and, therefore, it may be either harmful or harmless. In general, independent on the origin of municipal solid waste, its impact on the environment and different life forms affects pollution of air, water, and soil. Moreover, impact of municipal solid waste on land use, odors, and esthetic aspects has also accounted for holistic considerations of waste treatment systems.

In principle, the human species is on top of any environmental pollution and consequently constitutes the major factor endangering nature's biodiversity. Global population growth and increasing consumer demands, especially in strongly growing, emerging, and developing economies, have resulted in a large production increase worldwide. However, most industrial facilities have insufficient or completely lacking monitoring of their production processes in environmental terms, and often insufficient or inadequate facilities for management and treatment of waste. The global trend of rapid urban growth has further caused an increase of waste generation from private habitation sites and private and public service facilities; in addition, intensified construction and demolition activities are ongoing. As urban population density is generally very high all over the world, the daily consumption of goods and services is also high in urban areas. Additionally, the amounts of accruing municipal solid waste are also directly correlating with the economic status of the society in a given country [5].

Municipal solid waste generation *per capita* has increased in most of the countries globally; in many cases, this increase has been dramatic especially during the last years. Among all solid waste, plastics, paper, glass, and metals are the four categories of highest potential for recycling. The huge quantities of municipal solid waste are not only a severe ecological hazard but also cause major social concern. This makes it clear that appropriate municipal solid waste management is a current topic of utmost importance [6].

3. Composting of municipal solid waste

Because of diverse shortcomings such as the lack of waste segregation already at the origin, insufficient treatment, scarce reuse, lacking recycling systems, and often inappropriate disposal, solid waste management still has various gaps in the management chain which need to be filled. Treatment of the organic waste fraction for energy and resource recovery changes its physical and chemical characteristics. In this context, the most important processing techniques encompass composting (aerobic treatment) or bio-methanogenesis (anaerobic treatment in biogas reactors). Composting through aerobic processing produces compost as a stable product, which is broadly utilized as manure and as soil fertilizer and soil conditioner.

Due to various reasons, composting facilities are used to a lower extent in large metropolitan cities. Prevalence of unsegregated waste and production of low-quality compost resulting in low end user acceptance are the two most important reasons for this underutilization. Bio-methanogenesis via microbiological activity under anaerobic conditions generates biogas rich in methane as the value component. In general, composting becomes feasible when a given waste contains high moisture and high organic content. Uncontrolled and arbitrary disposal of mixed waste including organic fractions that cause environmental problems such as land pollution and pollution of soil and aquatic environments due to leaching of waste components [7].

An exemplary study assessing a new industrial process for mechanical-biological treatment of municipal solid waste reports that municipal solid waste received for treatment on the plant typically consists of, based on the dry mass, 9% of rejectable waste, 21% of fines (<20 mm) (mainly rejectables), 23% of paper and cardboard, and 15% of diverse plastic materials originating from petrochemistry. Such high content in plastics, paper, and cardboard is typical for the local situation (suburb of Mende, Lozère, France), where municipal solid waste is collected based only on a source separation of glass and complex residual waste, without separately collecting plastic, paper, and cardboards [8].

4. Types of municipal solid waste

A classification of solid waste sources can be accomplished based on the following assumptions:

i. All solid waste produced within a municipality's territory, independent on its physical and chemical nature and source of generation, is classified as "municipal solid waste" (**Figure 1**).

ii. All economic activities create a given solid waste pattern.

iii. Due to the fact that economic and consumers' activities cause generation of solid waste, all these activities are considered sources of solid waste [9].

Private households, hotels, offices, stores, educational, and other institutions are causes of municipal solid waste generation. The lion's share of solid waste encompasses organic (mainly food or horticulture) waste, cardboard, paper, plastics and other resins, textile rags, metal, and glass; in many cases, even demolition and construction debris is included in collected waste, in addition to certain quantities of precarious waste, such as batteries, electric light bulbs and fluorescent tubes, automotive parts, expired medicines and other pharmaceutical

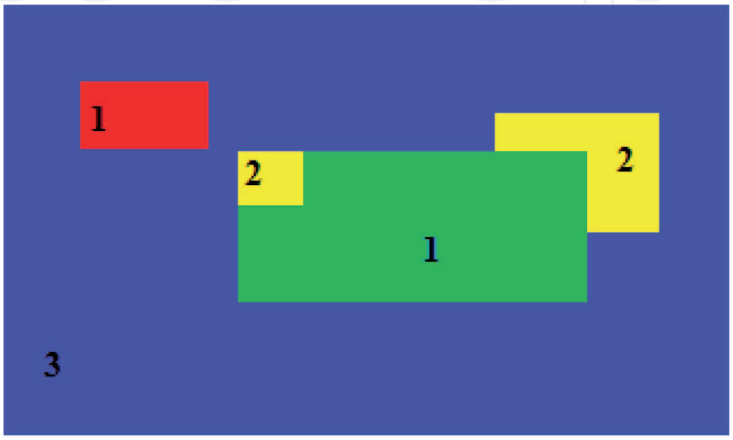

Figure 1.
A hypothetical urban municipality and the geographic areas (1. Urban, 2. Industrial, 3. Rural) where solid waste is generated [9].

Source	Typical waste generators	Types of solid wastes
Residential (private sector)	Single and multifamily habitations	Paper, cardboard, food wastes, plastics, textile rags, leather, yard waste, glass, lignocelluloses (wood, grass, and lopping), metals, ashes (heating and tobacco products), special wastes (e.g., bulky items, white goods, electronic parts, batteries, car tires, waste oils), and diverse types of precarious household waste
Industrial sector	Light and heavy manufacturing companies, fabrication, power and chemical plants, construction sites	Housekeeping waste, different packaging materials, food waste, construction and demolition materials, ashes, hazardous waste, and special waste
Commercial sector	Stores, markets, gastronomy, hotels, office buildings, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, and hazardous waste
Institutional sector	Schools, universities, kindergartens, hospitals and other health and medical institutions, penitentiaries, government centers	Same as for the commercial sector
Construction and demolition sector	New construction sites, renovation sites, road rehabilitation, demolition of buildings	Wood, steel, asphalt, cement, insulation materials, dirt, dust, etc.
Municipal services	Street cleaning, parks, landscaping, beaches, groves, playgrounds, sport facilities, other recreational areas, and wastewater treatment plants	Street sweepings, landscape, tree- and bush trimmings, different waste accruing in parks, beaches, riversides, and other recreational area, sludge after flooding events
Processing sector	Heavy and light manufacturing, chemical plants, (bio)refineries, power plants, mineral extraction and processing, joinery, and veneer works	Industrial process waste, saw dust, scrap materials, off specification products, slag, and tailings
All of the above should be included as "municipal solid waste"		
Agro-industrial sector	Farms, crops, orchards, vineyards, dairies, feedlots, distilleries, rendering and animal processing industry, biodiesel industry, and bioethanol production	Agricultural wastes, spoiled food wastes, animal residues (slaughterhouse waste), hazardous wastes (e.g., pesticides, antibiotic residues), and crude glycerol

Table 1.
Sources and types of solid wastes [10].

products, and diverse chemicals, e.g., cleaning and cosmetic products [10]. Hence, the main sources of solid waste are private households and the agricultural, industrial, construction, commercial, and institutional sectors. An assignment of different types of solid waste to their individual sources is shown in **Table 1**.

5. Municipal solid waste management

In parallel to the increase of population and economic activity, solid waste management is turning into a severe issue for almost all municipalities. Public health, odor disturbance, hazardous gas emissions, air pollution, or particulate matter formation are typical phenomena prevailing in urban regions. For smart management, municipal solid waste disposal requires proper environmental monitoring during

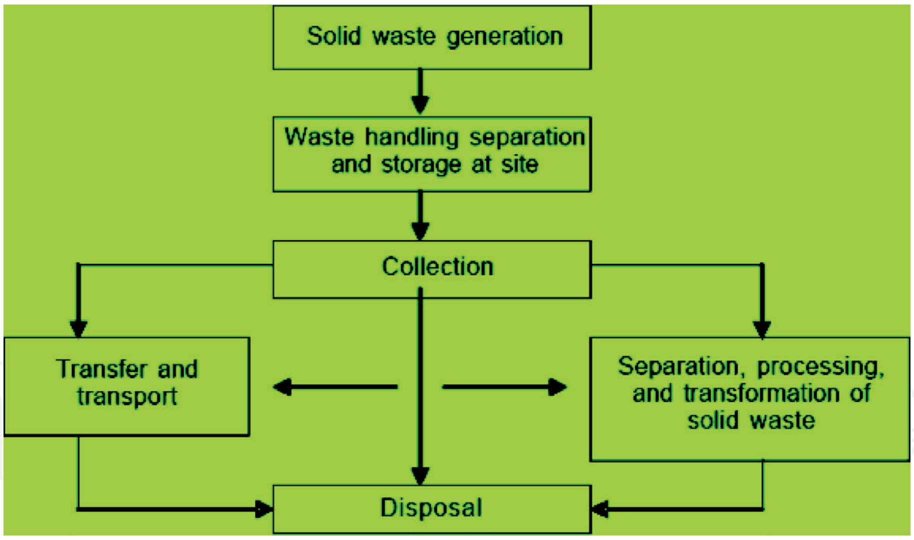

Figure 2.
Schematic of solid waste management system [12].

the entire waste treatment chain from waste collection to its ultimate disposal, and, finally, a regular control of disposal sites is needed [11].

To manage solid waste in an efficient fashion, the interrelationships of four functional elements have to be taken into account before a decision about an ultimate disposal strategy can be made. As reported by Shah [12], the first function element refers to the material generated at the source. Materials to which no more value is added are referred to and disposed as waste; quantity and nature of different types of waste are dependent on the waste source. The second function element encompassed the handling, separation, and storage at site of waste. In this context, waste has to be subjected toward separation before being placed into suitable storage containers. Paper, cardboard, packaging plastics, glass, ferrous metals, aluminum cans, and organic waste are those components, which typically are separated and stored individually. This step is crucial before moving to the next point. During the collection process, solid waste is picked up and placed into empty containers, which have separate compartments for recyclable materials [13]. Subsequently, the refuse collection staff collects the waste around the disposal centers manually before disposing it at the disposal sites. **Figure 2** illustrates the individual steps involved from waste material generation at its source until the final functional element for ultimate waste disposal.

6. Scenarios of municipal solid waste management

A policy for proper waste management needs to be grounded on the principles of sustainable development, which considers the society's refuse not only as rejects but also as a potential resource, which can undergo upgrading for potential value creation. In urban regions, appropriate solid waste management facilities are essential for, on the one hand, environmental management and protection and, on the other hand, for public health. Strategies and techniques for solving waste problems on a regional scale inevitably have a large number of possible solutions in order to be implemented in different areas, which are characterized by variable population densities, different life standard and life style, number of locations for waste management infrastructure, and number and types of protected landscape areas and other high value ecological sites. Environmentally benign waste management depends on various site-specific factors such as the composition of the waste, efficacy of waste collection at its source and of processing systems required to carry out different waste management techniques, feasibility of value-added material recovery from waste streams, emission standards to which waste management facilities are designed and operated, overall cost efficiency, and social performance of the community [7]. Due to this high complexity, municipal solid waste management has attracted a great deal of attention especially in countries with highly dynamic economic development such as India, a country that produces an estimated quantity of 50–600 million tons of municipal solid waste per year [7].

7. Municipal solid waste life cycle assessment

Life cycle assessment (LCA) is a process analytical tool recommended in many EU documents, e.g., the Directive 2008/98/EC on waste and certain other directives. LCA as a tool supports or enables the holistic consideration of the environmental impact of a new product or process already in its infancy, hence, during development [14]. As a quantitative measure, the Sustainable Process Index (SPI) allows to compare in a straightforward way the ecological footprint of products, processes, and systems based on the area required for completely embedding a process/system into the ecosphere [15]. Hence, LCA is a well-established tool, which nowadays is widely used to assess the environmental impact of product life cycles ("cradle-to-gate" or "cradle-to-grave"; the first refers only to production until the product leaving the factory's gate, while latter involves also the waste disposal after a product's life span), new technological processes, as well as waste management systems including waste treatment and processes for disposal, recycling, composting, or waste conversion for energy generation (biogas, thermal conversion in cogeneration plants). The evaluation of the existing situation of municipal solid waste management from an environmental, economic, and social perspective via a life cycle approach is an important first step prior to taking any decisions on the technologies to be selected, the policies to be developed, and the strategies to be followed for a nation [16].

The considerable number of reported LCA computer models dedicated to municipal solid waste management, often resorting to the SPI quantification tool, emphasizes the applicability of LCA in issues related to municipal solid waste management systems. Typically, these models have been developed independently from each other and are often based on features and assumptions that are highly specific to the period, economic framework, and geographical conditions in which they were developed. This clearly emphasizes that the assessment of feasibility of a given solid waste management systems needs to be in accordance to the individually prevailing conditions in a specific city or region.

Author details

Hosam M. Saleh[1]* and Martin Koller[2]

1 Radioisotope Department, Nuclear Research Center, Egyptian Atomic Energy Authority, Egypt

2 Institute of Chemistry, Office of Research Management and Service, University of Graz, NAWI Graz, Graz, Austria

*Address all correspondence to: hosamsaleh70@yahoo.com

References

[1] Abdel-Shafy HI, Mansour MSM. Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egyptian Journal of Petroleum. December 2018;**27**(4):1275-1290

[2] Scaglia B, Salati S, Di A, Carrera A, Tambone F, Adani F. Short mechanical biological treatment of municipal solid waste allows landfill impact reduction saving waste energy content. Bioresource Technology. 2013;**143**:131-138. DOI: 10.1016/j.biortech.2013.05.051

[3] Scaglia B, Adani F. Sustainable landfill and biological stability of municipal solid waste. In: Lavelle JR, editor. Waste Management: Research, Technology and Developments. USA: Nova Science Publishers, Inc.; 2008. pp. 193-223

[4] Zhang DQ , Tan SK, Gersberg RM. Municipal solid waste management in China: Status, problems and challenges. Journal of Environmental Management. 2010;**91**:1623-1633

[5] Shekdar AV. Sustainable solid waste management: An integrated approach for Asian countries. Waste Management. 2009;**29**:1438-1448

[6] Karak T, Bhagat RM, Bhattacharyya P. Municipal solid waste generation, composition, and management: The world scenario. Critical Reviews in Environmental Science and Technology. 2012;**42**:1509-1630

[7] Ramachandra TV, Bharath HA, Kulkarni G, Han SS. Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India. Renewable & Sustainable Energy Reviews. 2018;**82**:1122-1136

[8] Bayard R, de Araújo Morais J, Ducom G, Achour F, Rouez M, Gourdon R. Assessment of the effectiveness of an industrial unit of mechanical—Biological treatment of municipal solid waste. Journal of Hazardous Materials. 2010;**175**:23-32

[9] Buenrostro O, Bocco G, Cram S. Classification of sources of municipal solid wastes in developing countries. Resources, Conservation and Recycling. 2001;**32**:29-41. DOI: 10.1016/S0921-3449(00)00094-X

[10] Types of Wastes. World Bank; 1999. pp. 170-194. Available from: https://www.unescap.org/sites/default/files/CH08.PDF

[11] Chiemchaisri C, Juanga JP, Visvanathan C. Municipal solid waste management in Thailand and disposal emission inventory. Environmental Monitoring and Assessment. 2007;**135**:13-20

[12] Shah KL. Basics of Solid and Hazardous Waste Management Technology; Upper Saddle River, N.J.: Prentice Hall; 2000

[13] Tarmudi Z, Abdullah ML, Tap AOM. An overview of municipal solid wastes generation in Malaysia. Jurnal Teknologi. 2012;**51**:1-15

[14] Niederl-Schmidinger A, Narodoslawsky M. Life cycle assessment as an engineer's tool? Journal of Cleaner Production. 2008;**16**:245-252

[15] Narodoslawsky M, Krotscheck C. The sustainable process index (SPI): Evaluating processes according to environmental compatibility. Journal of Hazardous Materials. 1995;**41**:383-397

[16] Kulczycka J, Mineral T, Lelek L, Mineral T, Lewandowska A. Life cycle assessment of municipal solid waste management—Comparison of results using different LCA models. Polish Journal of Environmental Studies. 2016;**24**:125-140. DOI: 10.15244/pjoes/26960