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Abdelazim M. Negm
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Waste Management in MENA Regions

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Preface

This book is divided into 20 chapters, written by more than 26 researchers, scientists and waste management experts from several countries, who have a good experience in the region. One goal of the book is to demonstrate the waste management situation in several countries in the MENA region and to highlight some important experience and successful case studies which reflect waste management challenges and several waste management solutions in the MENA region.

Waste management in the MENA region is a critical issue. Since years ago, there have been significant changes in the waste sector's operational environment in the region due to the Arab Spring which lead to internal and external migrations in many countries; this has dramatically increased the pressure on the infrastructure in general including waste management, increased the pollution and resulted in rapid urbanization in the host countries to create an additional environmental and economic problem. Therefore, this unique book was a must to help the MENA countries to achieve the sustainability agenda 2030 in the waste management sectors.

However, many chapters in this book have showed that some countries started to improve their waste management service and adopted new strategies for reaching MDGs, by applying some advanced environmental technologies and extending recycling and reuse. But this was very limited and not sustainable. Other chapters in this book reflect that the solid waste sectors in the region suffer from chronic problems and face many challenges in terms of waste management service and technologies implemented to improve its waste management. The typical problem in municipal solid waste management in the region can be identified as limited utilization of recycling activities, centralized waste management in several waste sectors in the region, insufficient service in collection system, lack of management of hazardous and healthcare waste, insufficient landfill capacity and operational inefficiencies of services. Therefore, it was clear from the chapters that the waste management challenges in the region are common, similar and summarized but not limited to the followings:

- Most waste sectors in the region have centralized waste management in terms of planning, determining tariffs, regulations and laws that regulate the customer service which can be developed by reforming waste sectors to be decentralized to enable it providing good service.
- Impact of political instability in the MENA region because of internal and external migrations—this increases the waste sectors' stress.
- Limited involvement of national private sectors in the waste management in most of MENA countries—this makes a high pressure on the municipalities' countries.
- Limited economic and financing sources have also a negative effect on the waste management quality and service in the region.
- The urgent need of waste management sector in most of the MENA countries to private sector involvement and investments to achieve the sustainable development goals.
- Reform waste management sectors are needed to improve its service in many countries in the region.

Building on these above circumstances and to overcome those challenges, sustainable waste management has to consider all possible options for the reduction of the negative impacts of consumption and its pollutions. Therefore, political strategies in the region have to reform waste management escorts in the region, to change the centralized waste management into emergency plan to enable the decision-makers and related stakeholders, to adopt the effective and efficient solutions. Also improving waste management quality and service by involvement of national private sector in investment and operation/maintenance of waste management sector and in infrastructure in general.

Special thanks to all who contributed in one way or another to make this unique high-quality book a real source of knowledge and up-to-date findings in the field of waste management in MENA countries including Morocco, Tunisia, Egypt, Lebanon, Palestine, Syria, Jordan and Yemen. We would like to thank all the authors for their contributions. Without their patience and efforts in writing and revising the different versions to satisfy the high-quality standards of Springer, it would not have been possible to produce this book and make it a reality. Much appreciation and great thanks are also owed to the editors of the Earth and Environmental Sciences series at Springer for the constructive comments, the advices and the critical reviews. Acknowledgements must be extended to include all members of Springer team who have worked long and hard to produce this book and make it a reality for the researchers, graduate students and scientists in MENA countries and around the world.

The book editor would be pleased to receive any comments to improve future editions. Comments, feedback, suggestions for improvement or new chapters for next editions are welcomed and should be sent directly to the volume editors. The emails of the editors can be found inside the book at the footnote of their chapters.

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Chapter 1
Introduction to the "Waste Management in MENA Regions"

Abdelazim M. Negm and Noama Shareef

Abstract The situation of waste management in almost all countries of MENA regions is characterized by insufficient jurisdiction, lack of control, and technical and financial resources. Waste management is limited to collection and transport. The toxic waste from industries and hospitals is mixed with household waste collected, transported, and deposited. In order to help the decision-makers and stakeholders solve these problems and reduce environmental impacts, the book (Waste Management in MENA Regions) is introduced to provide an assessment and presents some suggestions to improve the legal, technical, financial, and organizational measures in the MENA regions countries. Almost all MENA regions countries have a similar legislature framework, and many countries faced similar challenges within the waste management sector. However, countries in this book have high needs to manage their waste in more sustainable way. The chapters in the books are country-based arranged from West to East. It starts by Chap. 2 from Morocco, Tunisia, Egypt, Palestine, Lebanon, Syria, Jordan, Yemen and then the summary of a few chapters related to all or some of the MENA countries. Consequently, this chapter is an introduction to this book. It provides an overview of the waste profile of the MENA countries. Also, the chapter presents a summary for each chapter following the same order of the chapters in the contents of the book.

Keywords Waste · Management · Solid · Innovative · Technologies · Treatment · Morocco · Tunisia · Egypt · Palestine · Lebanon · Syria · Jordan · Yemen · Biomass · Biogas · Logistics · Waste thermal treatment · Mechanical biological

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1.1 Introduction

Waste management (specifically solid waste) in MENA regions is one of the major challenges in the last two decades because of increasing solid waste quantities which are becoming a big problem in almost all countries of the Middle East and North Africa (MENA) region [1].

On the other hand, it is expected that the economic growth in the MENA region is raised from an average of 1.4% in 2017 to an average of 2.0% in 2018 which refers to a good economic situation in the region. On the other hand, the positive impact of reforms many sectors in the region improves sectors like reforms of domestic waste, water, wastewater, and the environment [2]. This opens a great window to start thinking in wise management of the solid waste management particularly if we know that the generated solid waste is mainly of biodegradable organic matter with more than 60%, and therefore is suitable for composting (see Fig. 1.1 and Table 1.1). Unfortunately, composting did not yet sufficiently developed in the region. This leads to think about recovering the organic matters from solid waste by production of compost, which is an important treatment technology of recovering organic matter and an essential method of disposal, and especially it is needed as fertilizer in many countries [3].

Consequently, MENA regions countries may think to use mechanical biological waste treatment (MB) plants which are needed to produce high compost quality and to produce high calorific value of special waste which can be used as a fuel (energy resource), or can be added to the cement industry. Also, this need is viewed as a result of the lack of good experience with sorting of recyclable materials from a big amount of solid waste produced in the region and processing of the separated organic matter to compost and safely reuse it.

Table 1.1 shows that Egypt produces the highest amount of waste in the region, of 21 million tons/year, and the country Mauritania generated the lowest in the region, which is about 454,000 tons/year. In the countries Yemen and Mauritania which

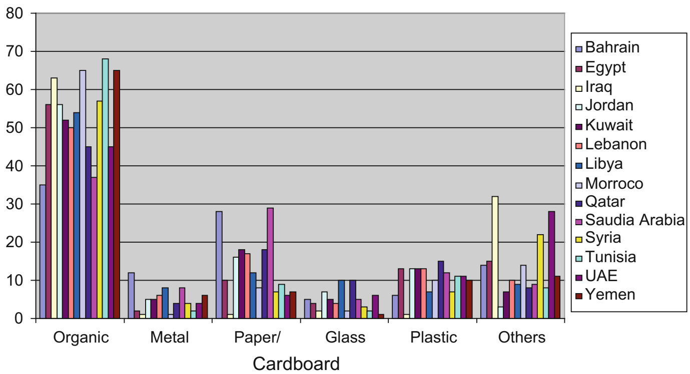

Fig. 1.1 Physical composition of municipal solid waste in some countries in the Arab region [4]

Table 1.1 SWM situation in the MENA region after Regional solid waste exchange of information and expertise network in the MENA region [5]

SWEEP-Net partner countries	Waste generation (tons/year)				
	Municipal	Medical	Industrial	Hazardous	Agricultural
Tunisia	2,400,000	16,000	116,000	150,000	4,000,000
Egypt	21,000,000	28,300	6,000,000	260–500,000	30,000,000
Morocco	6,900,000	21,000	1,5000,000	290,000	–
Yemen	3,800,000	4,000	–	21,000	–
Mauritania	454,000	1,200	–	–	–
Palestinian	1,400,000	3,200	132,000	63,000	440,000
Jordan	2,100,000	4,000	–	45,000	>4,000,000
Lebanon	2,000,000	25,000	6,000,000	3,400,00	–
Algeria	8,500,000	37,000	2,500,000	325,000	–

expected that more than 50% of the population are living in rural/urban areas, and generate 180–675 kg/capita/year. In addition to that, the collection system of solid waste coverages varies between 30% in Mauritania and reaching as high as 95% in Lebanon [5].

The nineteen chapters of the book provide an assessment of the current situations of the waste management in MENA regions and introduce some practical and technological solutions to help facing the waste management challenges in the MENA regions.

1.2 Summary of Chapters

1.2.1 Morocco

Chapter 2 discusses the management of solid waste issues in Morocco. It focuses on the management of solid wastes in Morocco. It gives an overview of the main activities generating solid wastes and the amount produced by year as well as the ratio per capita. The authors outlined the impact of solid waste deposit in non-controlled landfills and the efforts deployed to solve the problem, including institutional, administrative and legislative actions, and national strategies to cope with the issue. The implantation of these regulations obeys the general law of environment and other ramified laws and decrees related to specific issue. Adhesion of Morocco to different international conventions and the active contribution of private sector and NGOs are improving the collection and the management of solid waste taking into consideration the socioeconomical status of pickers.

1.2.2 Tunisia

Chapter 3 discusses the waste management in Tunisia considering the experience of the past. It is meant to be a retrospective analysis of waste management sector in Tunisia emphasizing lessons learned from the past that may help go forward, while the country is undergoing a transitional political, institutional, and economic phase. It gives a general insight into the sector underscoring milestones and highlighting the main achievements accomplished since the 1990s on various levels including regulatory institutional, financial, and technical. Initiatives within the public–private partnership and sensitization for the general public are the key elements for the sector to progress. The chapter also underscores several obstacles that need to be overcome and sheds light on new concerns, i.e., the emerging pollutants that could be of high potential impact on health and the environment. It was revealed that despite the large progress accomplished by the past, numerous challenges have to be overcome especially after 2011. In conclusion, it showed that Tunisia has progressed substantially in managing solid and liquid wastes in the time span of almost two decades. However, currently, the degradation of the environment is calling for stronger leadership and enforcement of the measures already untaken. Decentralization of decision-making and the growing role of the civil society are among the assets that government should support and promote. Lessons learned from the past call also for creation and raising awareness toward pollution prevention; the latter is not only a matter of applying high technologies, it can also consist in local innovative actions as leverage to society and the environment.

1.2.3 Egypt

Six chapters are presented from Egypt as it produces the largest amount of solid waste in MENA regions. Chapter 4 discusses the pre-management issues which deal with detection and prediction of geo-environmental hazards in urban areas and desert lands using an integrated structural and geophysical approach with the cases from Egypt to carefully consider the elimination or minimization of these hazards. The main features of this chapter include the following:

(a) This chapter focuses on introducing a non-conventional integrative approach of remote sensing, structural data, and geophysical methods for geo-environmental hazards assessment.
(b) The chapter presents case studies on detection and prediction of environmental hazards from human activities where contaminants are accumulated and spread on or beneath the ground surface.
(c) The following techniques are used to achieve the objective of the chapter: (1) remote sensing, (2) information on structural geology, (3) direct current (DC) resistivity method, and (4) airborne geophysics.

(d) Regarding the present case studies, the results indicate the effectiveness of the suggested approach to map surface and subsurface geological conditions concerning the pollutants and radioactive emissions in 2D/3D dimensions.
(e) Accordingly, the present approach will be helpful to the decision-makers to achieve sustainable development in urban and desert areas regarding the waste management aspects.
(f) The approach is recommended to update geohazards assessment in desert urban areas once surface and subsurface date become available to be integrated. Furthermore, the suggested approach is recommended for new urban areas especially those with limited fund, to develop the geo-environmental and geotechnical assessment.

Chapter 5 is about phytomanagement in Egypt as a sustainable approach for clean environment coupled with meeting the future energy demand. It focuses on the dual application of bioenergy plants to detoxify polluted sites (phytoremediation) and to derive beneficial phytoproducts such as bioethanol, bio-oil, fiber, wood, charcoal, and biogas. The chapter presents the strategies of phytoremediation processes including phytodegradation, phytovolatilization, phytoextraction, phytostabilization, phytofiltration, and rhizodegradation. The chapter uses various tools and methods to describe the removal mechanisms of heavy metals and organic and inorganic contaminants from soil via plant-based technologies. The chapter concludes that the common pollutant removal mechanisms are breakdown, transformation, volatilization, assimilation, uptake, absorption, translocation, accumulation, and storage. The harvested plant portions can be employed to produce energy through complete combustion, gasification, pyrolysis, or anaerobic digestion technologies. The chapter recommends further investigations on the socioeconomic, environmental, and commercial feasibilities of phytomanagement in combination with biofuel production. Moreover, genetic engineering and biotechnological tools should be used to screen new bioenergy crops that have the ability to thrive in the severe environment, capture and accumulate elevated amounts of contaminants, and attain high biomass production and growth rates. The interaction between plants, microbes, soil particles, and heavy metals in the rhizosphere should be completely defined.

Chapter 6 presents the technical efficiency of organic herbs in Egypt. The main purpose of this chapter is to compare the efficiency ratings of organic and conventional herbs and spices farms in the Egyptian delta. Organic farmers, on average, are found to be more technically efficient than their conventional counterparts (efficiency ratings are approximately 0.75 and 0.91, respectively). Hence, the results suggest that, by using available resources more efficiently and without changing current technology, organic (conventional) farms can increase their output by about 9% (25%). Concerning the factors influencing technical efficiency, they are found to be relevant. However, the main challenge faced by herbs and spices (H&S) processors and exporters is the lack of the research and development investments that lead to the limited benefit of creating high value-added H&S products. The most important H&S products produced in Egypt are fennel, marjoram, basil, peppermint, spearmint, and chamomile. According to the Egypt, Herbs and Spices Market Research Report—-

Forecast to 2023 report in 2018. The spices market is the dominant market, with its size reaching 82.8% compared with the herbs market. The main packaging material used is plastic achieving 58.3% compared with paper and other materials. The dominant distribution channel is store-based with a concentration of 84.8%. The Egypt herbs and spices market reached a valuation of 94.8 million US dollars in 2017 and is expected to display a compound growth rate of 3.27% annually for the period from 2018 to 2023.

Chapter 7 discusses the topic of biogas production (as a clean energy source) from kitchen wastes with a special focus on kitchen and household wastes in Egypt. Therefore, biogas definition and the advantages of its production are explained with focusing on the suitable wastes and the mechanism for biogas production. The biogas digesters (units) are highlighted. Kitchen wastes, its quantity, characteristics, and composition are presented. The anaerobic digestion, as the main process in biogas production from kitchen wastes, is explained with focusing on the limiting factors of the process. Consequently, the pretreatments of kitchen wastes for avoiding emerging some materials, such as volatile one as well, for improving the substrate characteristics for anaerobic digestion are presented. Also, other benefits of biogas production from kitchen wastes are reported. The focusing on road map for Egypt for biogas production from kitchen wastes will also be highlighted.

Chapter 8 presents the related issue on the management of agricultural wastes for climate change mitigation. It focuses on how increasing greenhouse gases such as CO_2, N_2O, and CH_4 affect on the climate negatively. These could be produced from sources such as burning agricultural wastes (such as crop residues, agricultural industrial residues, animal wastes). Consequently, in this chapter, the definition, sources and composition of agricultural wastes and the obstacles facing the effective utilizing of these wastes are presented. Also, the chapter discusses wastes and climate change in terms of their quantities and gas emissions from their burning or misusing. In this context, waste management concept, zero waste management, and waste management goals for climate change mitigation are also highlighted. Consequently, traditional uses of agricultural wastes such as animal feeding, composting, mushroom production, and renewable energy sources are focused. On the other hand, modern uses of agricultural wastes such as bioplastic and concrete production are also highlighted.

Chapter 9 discusses the logistics of waste management with the perspectives from Egypt. The main features of this chapter include the following:

- With the increasing environmental awareness, demand for more efficient waste management solutions and approaches has increased. Waste management requires many logistical activities such as collection, transportation, separation, sorting, and cleaning.
- The chapter adopts the concept of “reverse logistics” that supports the circular economy concept by shifting from the open linear model of material flow to a closed material-energy cycle, which leads to a significant reduction in the economy entropy and the improvement of utilization rates. Another main issue addressed in

this chapter is planning and providing sustainable logistics activities that should fulfill the adequate economic, social, and environmental levels.

- The status of waste management in Egypt is discussed as a representative country of the MENA region. The performance of logistics of waste management is assessed in terms of waste collection, handling, storage, treatment, and disposal with considering the environmental and public health risks.

1.2.4 Palestine

From Egypt to Palestine, Chap. 10 discusses the issues related to solid waste management in Palestine. It focuses on solid waste management in Palestine. The problem of solid waste (SW) is one of the major environmental problems that Palestinian state is currently paying increasing attention not only to its harmful effects on public health and the environment and its distortion of the cultural aspect but also to its social and economic impacts. This chapter presents the current situation of solid waste management in Palestine by presenting the quantities of waste produced and the administrative structures managing the SW sector, the SW tariff used and description of the SW collection system, the SW transportation system and the final disposal system, and the cost of SW collection as well. This chapter determines the existing SW vehicles quantity and quality, as well as the size of the workforce in the SW management sector per ton. The Palestinian national strategy for solid waste management is presented until 2022 too. The national needs of equipment in 2022 are determined.

1.2.5 Lebanon

Chapter 11 describes the waste management in Lebanon with focus on the Tripoli case study. The main problem of solid waste management in Lebanon lies mainly in suitable locations for landfills, incinerators, sorting and composting facilities accepted by the population which can hinder the implementation of projects if it is not environmental friendly and its views are not taken into account. In fact, since the end of the civil war in Lebanon in 1992, the government is working toward the promotion of a comprehensive waste management plan that is compatible with the sociopolitical situation and translates the desired expectations into actions to reduce environmental degradation. It is worth to mention that the Lebanese legislations in this sector are superficial, contradictory, and unclear, especially with respect to the distribution of responsibilities and tasks between municipalities and other official authorities. However, recently, a draft law concerning integrated waste management is being prepared, valorization of waste is decided, waste to energy and the recycling and the composting processes are promoted. A case study from Tripoli is presented with focus on the period from 1999 to the present.

1.2.6 Syria

From Lebanon to Syria, Chap. 12 discusses how to reduce methane emissions from municipal solid waste landfills by using mechanical biological treatment (MBT) with focus on Wady Alhaddeh plant, Tartous, Syria. The chapter focuses on studying the feasibility and effectiveness of mechanical biological treatment of municipal solid waste in a way to reduce methane gas emissions compared to the indiscriminate dumping of municipal solid waste. It presents the composition and characteristics of municipal solid waste in Tartous governorate including the calculation of landfill without gas recovery, methane production, calculation of methane amount after mechanical biological treatment, reduction in methane emissions by mechanical biological treatment compared to the landfilling, and reduction in methane emissions by mechanical biological treatment compared to the landfilling. All calculations related to the determination of the methane content result from MBT of municipal solid wastes at Wadi Elhadi as well as that of landfill wastes, without pretreatment and landfill gas recovery. All calculations were done using equations mentioned in the IPCC guidelines.

Chapter 13 is focusing on minimizing the high energy consumption in thermal disposal of sludge and solid waste in Syria. Therefore, the aim of this chapter is to demonstrate the developing technologies as low-cost thermal sludge disposal applications in a stationary fluidized bed combustor (SFBC) together with the waste by using Fuel BRAM (fuel from solid waste). This means the possibility to have the energy for thermal sludge treatment from solid waste as fuel and evaluate the chemical compositions of the flue gas emissions to test and control any pollution. This means that we have observed the combustion process of different sludge with BRAM (from solid waste as energy) in a stationary fluidized bed combustor (SFBC) and compared its behavior. The combustion system DN400 was designed to realize a self-sufficient combustion (energy self-sufficient) and to control the concentration of exhausted emissions by measuring it before it comes out of the system. Also, the chapter presents the possibility to use this technology [thermal treatment/disposal of sludge and waste in a stationary fluidized bed combustor (SFBC) together in one unit, by using Fuel BRAM (fuel from solid waste)], and this was tested for three different sludge: untreated, anaerobic treated, and aerobic treated. Also, it was possible to control the concentration of exhausted emissions by measuring it before it comes out of the system.

1.2.7 Jordon

From Syria to Jordan, Chap. 14 focuses on the solid waste management in the Syrian refugees host communities in the northern region in Jordan. The chapter presents the current waste generation and composition for both Irbid and Mafraq which are considered urban and rural areas, respectively, based on the urbanization index. The chapter shows the relative comparison between several municipalities in the municipal solid waste composition in refugees hosting communities as well as the waste recycling rate. The chapter also presents a possible waste recycling model and opportunities to link the private waste picking activities with the public solid waste management sector at the local municipality and dumpsite levels. In this context, a participatory model to create income generation potentials for the most vulnerable groups in the society (Jordanian Citizen and Syrian Refugees) is concluded based on the chapter findings. The chapter recommends such participatory initiatives in order to reduce conflicts between Jordanian citizens and Syrian refugees through a joint involvement of both groups in waste recycling activities of the massively littered environment.

Chapter 15 presents innovation technologies in wastewater treatment with a cost-effective solution applied to a case study from Jordan. The chapter focuses on wastewater treatment and reuse, water quality including emerging pollutants, socioeconomic frameworks, a transboundary database, and decision support tools. It also focuses on application, developing and transferring some innovative wastewater treatment technologies in small scale with low energy consumption in Jordan Valley as an approach for integrated water resources management (IWRM). This was for the sustainable use of water resources and to insure the local water quality required, a cost-effective treatment, sustainability, and protection of public health. The development and adaptation of several technologies and solutions has considered the local conditions and climate change. Therefore, the chapter presents the strategies of IWRM which has great potential to improve water scarcity situations in regions such as the Lower Jordan Valley, to raise the awareness of decision-makers and stakeholders in Jordan on wastewater treatment and reuse for irrigations purpose, on the necessity to switch to more viable water consumption models as well as on possible solutions to face the challenges like water scarcity, also to support the country in designing and implementing sustainable water management policies at the national and local levels. In addition to the above, this will help the country to contribute to institutional strengthening, the development of the necessary planning and management skills, and the transfer of know-how related above technologies. This chapter also provides an experience of IWRM which aims at local implementation, knowledge, and capacity building.

1.2.8 Yemen

From Jordon to Yemen, Chap. 16 focuses on biomass waste in Yemen and its management and challenges. As an example, it introduces the reader to the potential of biomass as a resource for energy in general and how conversion techniques are subject to several social, economic, and structural challenges. It also describes the main features of existing biomass resources in Yemen including municipal solid waste and wastewater. Moreover, it gives an insight into municipal solid waste management in Sana'a and on economic coping mechanisms since the beginning of internal conflicts and the ongoing war in terms of improving recycling processes. On the other hand, the chapter entails the efforts of international and national agencies such as the World Bank, the Social Fund for Development, the GIZ, and others to promote biogas production in some areas of Yemen and how biomass conversion could be utilized efficiently to benefit the population through producing clean electric power. At the same time, it helps improving the quality of life in rural and urban settings. In addition, wastewater is discussed herein as a potential source of gray water for agricultural uses if treated efficiently.

1.2.9 MENA Countries

From individual MENA countries to groups of MENA countries, Chap. 17 discusses the sludge treatment and disposal in some MENA countries (Sytia, Egypt, and Jordan). It focuses on municipal sludge treatment and disposal practices in some MENA countries, and it describes various methods used for sludge treatment such as thickening, conditioning, dewatering, drying, aerobic or anaerobic digestions, and composting as well as the final disposal methods which include incineration, landfill, and land application. It also introduces the new technologies and trends in sludge management worldwide. It discusses regulations related to sludge treatment, reuse and disposal, to protect public health and the environment from any reasonably anticipated adverse effects of pollutants contained in the sludge. It introduces case studies of sludge management from some MENA countries include Syria, Egypt, and Jordan.

Chapter 18 presents different strategies toward three R's agricultural waste (reduce, reuse, and recycle) in MENA countries. It focuses on the management of agricultural wastes in the Middle East and North Africa (MENA) countries to avoid serious environmental concerns such as eutrophication of surface water, groundwater contamination, odor emissions, and deterioration of soil, water, and air. The chapter presents the strategies of agricultural waste management in the MENA region regarding the available land, water, and energy resources. It also demonstrates various tools and methods by assessing the threefold solutions of agricultural wastes, viz., reduction, reuse, and recycling.

Chapter 19 presented an integrated system for management and utilization of agriculture wastes in some MENA countries. It is worthy to mention that agriculture-based natural resources in the Middle East and North Africa (MENA) region are very fragile. The MENA region is characterized by high population growth, erratic weather conditions, limited area of arable lands, harshest deserts, and with acute water shortage. Many countries in MENA region are suffering from a shortage of raw materials which are very necessary for agriculture and industrial purposes. Exploitation of non-conventional resources such as agriculture wastes or residues for economic agricultural and industrial products is increasingly needed. Agricultural residues (AGR) are the secondary product of agricultural activities such as vegetative parts left after harvesting vegetables, fruit tree pruning, and wastes from food processing and agro-industries' by-products.

The chapter also aims at casting lights on potential management and usages of common agriculture residues (wastes) in some MENA countries. It focuses on the identification of potential AGR and common utilization technologies. Constraints and strategies for management and utilization are also discussed. The chapter also covers the following important topics: quantity of agriculture residues (AGR) in some MENA countries; technologies and utilization of AGR; novel value-added products from fruit and vegetable wastes; integrated approach for the utilization of AGR; general constraint encountering utilization of AGR; benefits, significance, and economic of agricultural residues utilization; capabilities of various MENA countries to utilize such materials and proposed strategies for AGR utilization in the region.

Since treatment and management of waste consume a lot of energy, Chapter 20 focuses broadly on the relationship of renewables to metrics such as levelized cost of energy (LCOE) to various types of renewables, especially in the MENA region. The authors begin by considering the relationship of LCOE to other parameters used by renewables to justify its competiveness compared to fossil fuels.

The authors also look more deeply at concentrated solar power (CSP) and desalination as a specific example of how these metrics can be used. The chapter views CSP as the best technology to address desalination since it captures 4X more solar energy than its competitor, photovoltaics and reverse osmosis (PV + RO), while the CSP coupled with MED desalination is particularly well suited to make clean water. It is worth mentioning that any structure that captures solar energy needs to be as low in cost as possible (capital cost) and as high in energy capture (LCOE) as possible.

The book ends with Chap. 20 which is devoted for the conclusions and recommendations from all chapters presented in the book.

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Chapter 2
Management of Solid Waste in Morocco

Abdelmalek Dahchour and Souad El Hajjaji

Abstract Growth of Moroccan population and the increase in economical activities are tightly associated with the increase in consumption that generates increasing solid waste (SW) production. Recent surveys reveal that the volume of SW produced in Morocco has exceeded 6.8 million cubic tons (MCT), including industrial wastes (1.6 MCT/year). Among the total, 85% of SW is regularly collected mainly in urban zones and disposed off in landfills. Only 37% of the collected SW is disposed off in controlled landfills. The absence of generalized action of SW management has led to non-civic behaviors and deterioration of the environment. Efforts have been deployed to improve infrastructure and the adoption of positive strategies aiming at "a zero-waste society" through different national plans at administrative and legislative levels. Their implementation obeys the general law of environment and the adhesion to several international conventions, sensitization, and educational actions. Association of the private sector and NGO represents essential pillars to achieve the goal targeted. In 2006, the first Solid Waste Law was promulgated, and an integrated strategy that includes a legal and institutional framework, and allocation of financial resources was launched. It aims at developing collection, treatment, sorting, storage, disposal, and recovery system, taking into account the specificities of the waste and the socioeconomical status of pickers.

Keywords Solid waste · Management · Valorization · Landfills · Law · Morocco

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2.1 Introduction

Moroccan population accounts for more than 34 million inhabitants, 51% of them are in urban zones. As in the other Mediterranean countries, Morocco has experienced regular growth in industrial activities and increasing demographic population associated with the increasing consumption that generates an increase in the volume of solid wastes (SW). Before the year 2000, Moroccan economical activity was based mainly on the agricultural sector. Industrial activities were limited to food industry and textile representing 15% of gross national product (GNP), employing 10% of active population, and ensuring 75% of exportations. Nowadays, these sectors represent more than 30% of GNP and employ 21% of active population [1].

In 2009, Morocco has launched a new industrial strategy PNE (emergency national plan) aiming at creating 220,000 jobs. The strategy aimed at diversifying and improving the industrial sector. The main sectors retained are offshoring industry, car industry, aeronautic, textile and leather, food industry, and integrated industrial platforms. Actions are implemented as PPP (public–private project) with clear and well-evaluated objectives, reliable engagement, and shared responsibilities. By 2015, PNE would achieve the followings targets: 220,000 jobs mainly among urban population, improve wealth by increasing GNP by five billion USD, and increase exportation by nine billion USD. This strategy was reinforced by the Industrial Acceleration Plan 2014-20. Achievement of these goals relies on different legislative and administrative stimulations, such as reduction or elimination of 24–36 months of income taxes, and reduction and elimination of five years of taxes on the enterprises.

2.1.1 Car Industry

This sector employs 56,300 persons in 135 enterprises in three main sites that are Tangier, Casablanca, and Kenitra. This sector contributes in the exportation volume by 2.2 billion USD. It is due to contribute for an economic turnover equivalent to 5.4 billion USD in 2017 compared with 1.1 billion USD in 2009.

Attraction of the main French operators, Renault and PSA, Chinese group BYD, and other investments amounted to 1.4 billion USD. These efforts will place the country among the seven top car manufacturers with an expected production of one million vehicles by 2020. The expected income is estimated to ten billion USD and creation of 160,000 direct and indirect jobs (Fig. 2.1a, b) [1].

2.1.2 Aeronautics Sector

This sector has shown a remarkable growth with the development of varied associated industries in wiring, mechanics, sheet metal work, composites, and mechanical

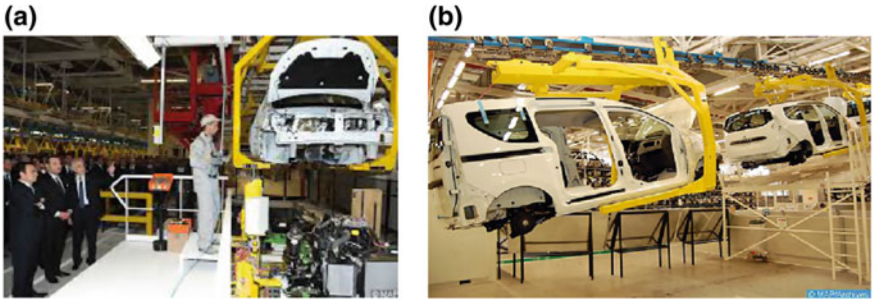

Fig. 2.1 His majesty the King Mohammed VI visiting a car industry unit

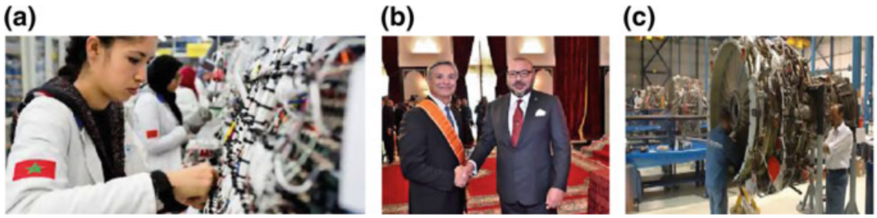

Fig. 2.2 Some views of aerospace industry in Morocco. In the middle, the King Mohammed VI shakes hands with Raymond L. Conner, Vice Chairman of Boeing

assembly, driven by the installation of global enterprises such as Bombardier, Eaton, Safran, Boeing, Airbus, and Alcoa. The investment of Bombardier is estimated at 200 millions USD would create 850 direct and 440 indirect jobs. Incentive actions include availability of the land, 100% tax exemption during the first five years of operations, and a reduced rate of 8.75% over the following 25 years [2]. The joint venture between Safran Electrical and Power and Boeing celebrated its 15th anniversary in 2016. Based in Casablanca, this company supplies some 140,000 wiring assemblies a year to Boeing, Airbus, Dassault, and other manufacturers, as well as wiring harnesses for the LEAP, CFM56, and GE90 engines (Fig. 2.2a–c).

2.1.3 Textile and Leather

The sector of textile and leather represented an employment rate of 40% of all Moroccan industries, with a significant contribution to the GDP estimated at 13%. It represented a deal of two billion USD in 2007 and has achieved 3.5 billion USD in 2015, mainly in fast fashion category. It is due to improve by 10% via the improvement of integrated production distribution channels, discovery of new markets, actions on rate of custom taxes, and building capacities (Fig. 2.3a–c) [3].

Fig. 2.3 Some views of Moroccan textile and leather products

2.1.4 Food Industry

This sector represents 35% of Moroccan GNP. It is dedicated mainly to local market (85%), while the remaining 15% is exported [4]. The main exported products are fish (600 million USD), representing 40% of Morocco food and beverage products exportation. Being the first exporter of sardine, and the third exporter in the world of agar-agar product, this sector has 796 units or factories and boats employing 75,000 persons. In the beverage industry, Morocco produces about 37 million bottle of wine (78% red wine, 18% gray and rose wine, 4% white wine) and 900,000 hl/year of beer mainly in the region of Meknes.

Milk industry is dominated by Centrale laitiere with 500 million liters per year (70% market share) and Copag Jaouda with 500,000 L/day (20% market share). Other trade names are present such as Chergui, Yogo, Jibal, and regional cooperatives.

Biscuit sector is growing up regularly at the rate of 17%. BIMO stands for the leader company with 48%. The improvement of this sector relies on Moroccan plan "Rawaj" to develop local trade plans by 2020: this will target the construction of 600 supermarkets, 50 hypermarkets, and 15 malls. This improvement will cope with the objective of twenty millions of tourists. Morocco launched a set of projects to develop the touristic sector (Azur plans). This development will create a demand for food and beverage industry products [5].

2.1.5 Mineral Industry

This sector contributes at 10% of GNP and 30% of exportations. In 2013, the production has achieved 33 million tons (MT) including 31 MT of phosphates rocks and its derivatives representing a value of 5.2 billion USD. Morocco is the world's leading exporter of phosphate with 12% of phosphate rock produced. The country was responsible for 16% of the world's arsenic output, 10% of barite, about 2% of cobalt, and 1% of fluorspar. Morocco also produced a wide range of minerals that include clay, copper, crude oil, feldspar, iron ore, lead, natural gas, pyrophyllite, salt, silver, talc, and zinc. Phosphate activity employs 41,000 people in 2013 and continued to be a major source of export earnings [6].

2.1.6 Solid Waste

The amount of solid waste generated has exceeded 6.8 million metric tons (MMT) representing 0.7 kg/d/cap in urban zone and 0.3 kg/d/cap in rural zone in 2013. More than 85% of SW is regularly collected in urban zone, totalizing 5.5 MMT. Only 37% of SW collected was disposed off in controlled landfills [7] and 20% was expected to be recycled in 2015. Industrial sector generates 1.6 MMT/year of SW including 290,000 MT hazardous wastes. Only 23,000 MT are collected, 8% of which are disposed off in uncontrolled landfills without any pretreatment. Medical and pharmaceutical wastes are estimated at 21,000 MT/year, 28% of which is dangerous wastes [8].

The absence of generalized management action of SW opens the way to various non-civic behaviors with negative impact on the environment. It is not surprising to see waste burning as a means of SW reduction in Morocco due to the lack of waste management infrastructure leading to potential health effect on the population. Efforts have been deployed to improve the infrastructure in terms of collection, controlled landfills, and treatment. By 2020, the number of controlled landfills is expected to increase from 14 to 30, while 84 deposits were planned for rehabilitation or remediation [8].

2.1.7 Strategies of SW Management

In this context, Morocco is aiming at the adoption of the strategy of "a zero-waste society" that match with the "three R's" rule (reduce, reuse, recycle) through a national plan of hazardous waste (2008–2022) for optimizing waste prevention and considering wastes as a resource within a green economy vision. Various actions that are being considered for the improvement of SW management include professionalization of SW collection by the involvement of the private sector, increasing disposal in controlled landfills, creating new or rehabilitate ancient landfills, including the social aspect at each step of these actions. At administrative and legislative aspects, various actions tend to improve the management of this sector. They aim at implementation of good practices of collection and disposal, treatment of hazardous wastes, strengthen partnership with private sector, encourage investment in SW field, building capacities to face for best management, and strengthen cooperation with Mediterranean countries. At legislative aspect, the law 28-00 provides the framework for governing the sector. It is accompanied by implementation of texts regulating specific areas of intervention. The law 12-03 on the environmental impact assessment provides a technical tool to assess the absence of any negative impact on the environment. The law on road transport regulating transportation of dangerous wastes has filled the gap of the legislation in terms of prevention and protection.

Administrative and legislative measures are not the only actions that could guarantee the successful of the SW management. Private sector and NGO are also associated

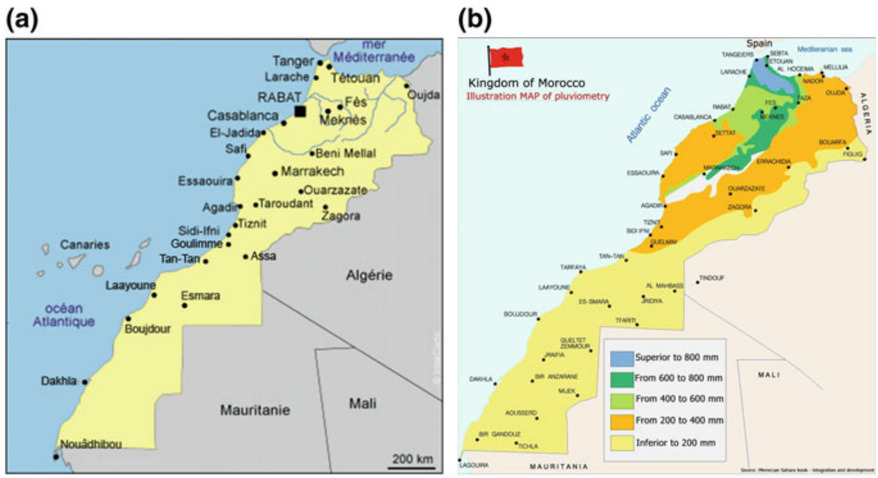

Fig. 2.4 Moroccan administrative (**a**) and rainfalls distribution (**b**) maps

with individual actions or through partnership actions. Some companies have taken initiatives to manage their SW. Others in the framework of consortium have taken sensitization and concrete such in the case of pesticide sector (CropLife). NGOs are also encouraged by the government via Mohammed VI foundation for the environment. Training sessions, salubrity campaigns, and workshops are regularly organized. Various actions have dealt with the collection and recycling of electrical, computer, and plastic wastes. Education on environmental protection is also another pillar that contributes to the management of SW through the creation of specific courses and credits at the universities.

2.2 Background Information About Morocco

2.2.1 Geographic and Demographic Information

Official statistical projections estimate population of Morocco at 35 million inhabitants in 2018 in 12 administrative regions covering 710,850 km^2, with a growing rate of 1.89 in urban zone against −0.31 in rural zones. Due to its geographic position, Morocco is under two main constraining climate conditions with well rain-fed regions to the northern part and dry region to the south (Fig. 2.4).

Table 2.1 Types of waste [9]

Waste type	Definition
Construction debris	Detritus minerals from construction and demolition
Organic waste	Biodegradable component of municipal waste (e.g., food and yard waste)
Domestic waste	Waste from private households
Household commercial waste	Waste from commercial establishments, businesses, the service sector, public institutions, and industries that possess similar characteristics than household waste
Commercial waste	Waste with characteristics similar to household waste
Municipal solid waste (MSW)	Household, bulky, household-like commercial, yard, open market, construction and demolition waste, street sweepings, etc.

2.2.2 Environmental Issue

Environmental issue has gained concern among official authorities since the early eighties. After his ratification of Kyoto Protocol, Morocco has adhered to all the international conventions related to environmental issues. He has strengthened his awareness by the creation in 1992 of a specific department in charge of the environment. The department was subsequently structured in different subdivisions in charge of specific aspects of environmental issue. This structure has generated different strategies to be implemented such as national strategy of the protection of environment and sustainable development (SNPEDD), national action plan for environment (PANE), national plan to control climate changes (PNCC), and national plan of waste management (PNDM). All these strategies were gathered in national act of environment issued in 2009 (law 99-12).

2.2.3 Solid Waste Issue

SW is a general terminology that includes large proportion of municipal, hospital waste, industrial waste, demolition waste, and hazardous waste. It is now commonly admitted that what is a waste from a process could be a source for another process. Waste is therefore acquiring a very dynamic concept. The term “waste” can have different meanings depending on the context. It is commonly admitted as “unwanted” by the person who discards it. Different international organizations like the European Union (EU97), Organization for Economic Cooperation Development (OECD98), and United Nations Environmental Programme (UNEP99) have their own approach to, and definitions of, the notion of solid waste [8]. Different types of waste could be considered as presented in Table 2.1 [9].

The production of SW is unavoidable. It becomes important due to the increase in settlements and communities. The increasing SW production represents a serious source of disease (plague and cholera) and health as is reported in Europe in the Middle Age. Methane released from the decomposition of biomass was behind more than 380,000 deaths in Hamburg [10]. Physicians, like the Greek scholar Hippocrates (around 400 B.C.) and the Arab Avicenna (Ibn Sina, 1,000 A.D.), were the first to link epidemics to contaminated water. Between 1347 and 1352, about 25 million people (nearly 30% of the entire population) died in Europe from disease [10].

Management of SW has been tackled by different actions in different countries. For instance, paving the streets and introduction of garbage cans were done in 15th century, and creation of the Public Health Act in England and construction of the first incinerators were done in 1876. Between 1850 and 1890 scientists (Ignaz Semmelweis, Louis Pasteur, Robert Koch) reveal bacteria and viruses as the causes of disease, in 1980 first breakthrough in integrated SWM: recycling, composting, and anaerobic technology are a priority for waste disposal [9].

This issue has gained more concern worldwide by organizing World Summit Sustainable Development (WSSD) global summits and increasing cooperation between countries. In June 1992, the United Nations Conference on Environment and Development (UNCED), Earth Summit was held and adopted a global action plan "Agenda 21" for international activities in environment protection. It was followed ten years later in August 2002 by WSSD to review the action plan and to discuss new challenges. Focus was made on developing integrated system solid waste management (ISSWM), placing utmost priority on waste prevention and minimization, reuse and recycling, and ultimately on environmentally disposal facilities, promoting waste prevention and minimization by encouraging biodegradable products [9].

In 2000, the general assembly of UN adopted the MDGs (millennium development goals) 2000. In 2004, G8 Summit suggested the "3R Initiative," meaning—Reduce, Reuse, and Recycle. This was completed by the protocol on Global Climate Change in 2005 and transboundary movement of SW.

Morocco has followed this trend in sustainable development by attending the different summits and creating a ministry dedicated to environmental issue. Morocco has ratified all the conventions related to this issue and promulgated laws for management of SW.

2.3 Potential of SW in Morocco

2.3.1 Domestic Waste

The production of domestic wastes per capita depends on the region and the disparities between urban and rural areas. Variations could occur among the same population group according to their standard of life in terms of accommodation and consumption.

Table 2.2 Mean production per capita (case of municipality of Youssoufia in Rabat) [11]

Zone in the municipality	Type of habitation	Production of SW
Z1	Villa of high standing	2
Z2	Villa and buildings. Mean and high	1.70
Z4	School, hospital, Low cost habitation, Rehabilitated anarchic + zone of activity	0.70
Z5	Low cost habitation	0.55
SZ6	Building (HLM)	0.50
Total		0.83–0.9 kg

Source Ministère Marocain de l'Aménagement du Territoire de l'Eau et de l'Environnement

Ratio of production varies from 0.4 to 1 kg/cap/d, corresponding to 7.6 MT/year in 2005 and 9 Mt (2015). A case story reported by Hafidi is presented in Table 2.2 [11].

On the basis of demographic growth and the rate of SW production (1%), the author has estimated the total production to reach 11,850,000 tons/year constituted by 8,400,000 and 3,450,000 tons from urban and rural areas, respectively [11].

2.3.2 *Properties of Domestic Wastes*

The composition of domestic waste depends on the style of life and type of consumed products. In Morocco, the main properties of domestic waste reveal:

- High percentage of water (60–70%);
- High content of organic matter (60–70% of weight);
- Increasing level of plastic and hard paper (5–10%);
- High density (0.4–0.5);
- Calorific power (P.C.I.) estimated to 900–1000 kcal/kg.

Due to the constant evolution of these properties, it suggests an appropriate model for management [11].

2.3.3 *Industrial and Dangerous Wastes*

The amount of SW generated by industrial sector is estimated to 1.6 MMT annually, of which approximately 260,000 T is hazardous waste. Hazardous waste stands for chemical wastes that could harm the health and the environment. They include explosives (ammonium nitrates, perchlorates, peroxides…), comburants, TNT, solvents, irritating agent, corroding agent, products lacrymogènes, toxic for reproduction, carcinogens, PCB, dioxines, furanes.

Table 2.3 Repartition of industrial solid wastes in Morocco [12]

Industrial activity	Industrial waste (T/year)		Total (T/year)	%
	Specific wastes	Hazardous wastes		
Chemistry and par-chemistry	844,528	103,174	947,802	60
Textile and leather		86,052	86,052	5.5
Electricity and electronic		3083	3083	0.03
Food industry	380,000	14,002	394,002	25
Metallurgy, energy	94,268	34,626	128,894	8.2
Other		15,108	15,108	0.95
Total	1,318,896	256,045	1,574,941	100

Only 23,151 T of the industrial hazardous waste is collected annually. Of this amount, 8% is disposed off in uncontrolled dumpsites and municipal landfills without prior treatment. The repartition of industrial waste is reported in Table 2.3 [7, 12]. On another hand, plans are now in place to establish a National Special Waste Treatment and Disposal Center (CNEDS), which will significantly improve the situation.

2.3.4 Medical and Pharmaceutical Waste

Medical wastes represent an important issue due to their potential as environmental hazards and their risks to human health. This type of wastes may contain infectious waste, toxic chemicals, and heavy metals, substances that are genotoxic or radioactive. Although the existing variation of management practices between hospital units, the risk of impact on health and environment remain similar.

In 2002, World Health Organization (WHO) conducted a study in 22 developing countries and revealed that 18–64% of healthcare facilities did not use proper waste disposal methods [13, 14]. In Morocco, a case study reported a survey in selected hospitals in Souss-Massa region and revealed low level of skills in management of dangerous wastes [15].

In Morocco, pharmaceutical waste is estimated at 21,000/year, of which 28% is hazardous. Not much official data are available or has been made publicly yet for special waste streams, such as packaging waste, green and agricultural waste, construction and demolition waste, waste tires, oils and lubricant waste, and e-waste or recycling. Although the qualitative and quantitative data will likely improve as the regulatory infrastructure strengthens, the sectors continue to transition from the informal to the formal, once the hazardous waste facility (CNEDS) has been built and comes online [7]. The medical waste management practice in Morocco is performed in accordance with the regulation of the Decree No. 2-09- 139 of 2009 that establishes definitions, principles and the procedures for separation, collection, transportation, storage and disposal of medical.

2.3.5 Agricultural Waste

Organic wastes generated by the agricultural sector and food industry have never been subjected to specific studies or statistics to assess their quantity. Despite the fact that organic wastes are full of enormous potential, their use is currently very limited. In Morocco, two main resources of agricultural waste are identified:

- Agricultural sector: crop residues, residues from trees, manure, roots, etc.
- Agro-industrial sector: by-products of agricultural products transformation such as bagasse and molasses (from sugar refining), margines and pomace (from olive crushing), oilcake (from soybean and sunflower processing), etc.

2.3.6 Food Losses and Waste (FLW)

Food losses waste is one of the most critical social, economic, and ecological challenges facing humanity. FAO data on FLW show that roughly one-third of the food produced for human consumption is lost or waste. In Morocco, more attention is paid to food losses, while food waste (FW) is generally ignored. A survey conducted by Abuabdillah et al. revealed that FW is widespread in Morocco as only 3.3% of respondents declare that they do not waste any food. About 39% declare that they throw away at least 250 g of still consumable food each week [16]. The same attitude was reported in Algeria mainly during Ramadan period (fasting month), 88% of respondents declare that FW increase during this month. Fruit and vegetable constitute the main FW lost [17]. Efforts should be directed toward consumers to cope with their food-related activities and to better consider the impact of food waste on the environment and economy [18].

Due to the variation in the chemical composition of this type of waste, their valorization process could not be done by the same techniques and needs preliminary study of their composition to adapt each bioconversion process with the suitable biomass [19]. To cope with this issue, Moroccan Ministry of Agriculture and Fisheries in partnership with the Food and Agriculture Organization of the United Nations (FAO) launched in June 11, 2015, a strategic project in order "to develop a national strategy and an action plan to reduce FLW in Morocco." The main activity consists of a study on FLW in the country to develop a vision in order to prepare an action plan to reduce FLW by 50% by 2024 [16].

Table 2.4 List of type of waste according to the law 28-00 [11]

Domestic waste	Waste generated by household and similar wastes generated by industrial, commercial or other activities
Industrial wastes	All waste different from domestic waste generated by industrial, mining, or other activity
Medical wastes	All type of wastes generated by diagnostic, follow-up of medical treatment for human and animal activities of public and private hospitals, research centers, laboratories of analysis
Agricultural wastes	All wastes issued from agricultural activities, food industry, or breeding
Dangerous wastes	Wastes containing or have some harmful properties to the population and to the environment. The list of dangerous waste is established by regulation
Inert wastes	Waste issued from the activities in mining, destruction, or restoration activity noncontaminated with dangerous substances, without any chemical or physical reaction. They are not degradable or not altered by other compounds
Ultimate waste	Waste generated or not generated by treatment of another waste at its ultimate phase and could not be treated with the available techniques
Biodégradable wastes	Waste that could be degraded by natural biological activity, either under aerobic or anaerobic conditions, as food wastes, waste from gardens, papers, and had paper
Déchets encombrants	Domestic wastes that have large volume or heavy weight that could not be collected by ordinary vehicles and need special collection mean
Wastes similar to domestic wastes	All wastes with similar properties and composition to domestic wastes generated by economical, commercial activities

2.3.7 Collection of SW

Collection process is the responsibilities of local authorities (communes and municipalities). In big cities, the process is delegated to private sector. Collection varies with departments and depends on financial, logistic, and infrastructure resources. It varies between 75 and 100% of the available SW. Two types of collection are currently used: free access to waste tanks deposited in the street and direct collection from the population. This remains under the expectations of international standards. Major insufficiencies have been noticed in this process, in terms of inappropriate collection equipment, noncontrolled landfills, nonprofessionalism management, no strategic plan, and lack of funds to improve the sector. Table 2.4 present the list of wastewater according to the law 28-00 [11].

Table 2.5 Rate of collection in selected urban zones [11]

Area of collection	Rate of collection (%)	Areas of collection	Rate of collection (%)
Fès	70	Ouazzane	96
Tétouan	80	Tarmight	70
Asilah	80	Larache	65–70
Laayoun	100	Tata	100
Agadir	100	Targuiste	80

Source Secrétariat d'Etat chargée de l'Eau et de l'Environnement-Département-2005

Due to the lack of an appropriate collection, treatment and disposal infrastructure, nearly all hazardous waste produced by the industrial sector is disposed off in uncontrolled dumps, municipal landfills, on nearby land, in abandoned quarries or along rivers, without any treatment or control. Informal operators are very active under this situation. Wastes are sorted out and resold as resources for other activities. This informal system has resulted in serious consequences of public health. Table 2.5 shows the rate of collection in selected urban zones.

The main constraints facing the collection of domestic wastes are:

- Lack of coordination and conscience among the population;
- Increasing amount of SW in the cities;
- Timing of the collection;
- Insufficiency of tanks compared with the volume of SW to collect;
- Lack of follow-up and monitoring of the management of SW collection;
- Failure in execution of the collection as planned;
- Insufficiency in the financial management of SW collection.

The rate of collection of SW depends on the communes and their financial logistic and financial infrastructure. To cope with this alarming situation, PNDM (national plan of domestic wastes) has been launched in 2008 to achieve the following objectives:

- Upgrading the sector of SW;
- Building partnership between Ministry of Environment and local authorities (communes, municipalities);
- Achievement of 90% of collection by 2020 and 100% by 2030;
- Creating 15 controlled landfills in all the main urban centers compared to six landfills prior to 2008, by 2020 to achieve 37% of municipal solid waste disposed compared to 10% prior to 2008;
- Closing or rehabilitating (26 landfills) wild landfills by 2020;
- Draw strategic plan for management of SW for all the regions and provinces;
- Upgrading the sector by modern management and professionalization. Collection rates by private companies in about 106 municipalities, providing service to over 74% of the urban population in Morocco;
- Improving capacity building of the intervening in the sector;

- Organizing section activity in order to achieve 20% of SW recycled and valorization processes;
- Dedicate social importance to waste pickers by inclusion initiatives of social concerns at all levels [7, 11].

The cost of the program was evaluated at four billion USD over a period of 15 years. The program is a collective contribution involving communes (73%), taxes (11%), State (9%), other (7%). The improvement of the infrastructure in the framework of PNDM relies on the eligibility of the stakeholder (commune) that should fulfill some conditions:

- Prepared solid waste management plan;
- Availability of land to establish the project to avoid any juridical constraint;
- Taking into consideration the social aspect;
- Having a preliminary study of the impact of the project on environment;
- Acceptance of inter-communal participation in the framework of local strategic plan.

In 2015, PNDM has satisfied about 18 millions inhabitants by achieving the following level of execution:

- 64 orientation plans have been launched, among which 13 were finalized;
- 23 wild landfills were rehabilitated;
- Professionalization of the collection at 86% compared with 46% in 2007;
- Rate of burning exceeding 40% against 11% in 2007 [11]

2.3.8 Attempts of Modeling Collection Phase

In order to improve collection phase, an optimizing model was suggested, taking in consideration the current year, the latest census population, and demographic growth rate (DGR), according to the following formula:

$$\text{Population(current year)} = (\text{Population(latest sensus)} + \text{DGR}/100)$$

To implement the model some corrections are introduced:

Municipalities with DGR below national mean, it is assumed that this rate will be achieved within ten years starting from the current year.

In that case of DGR higher than the national mean, it is supposed that this rate will decrease till the mean within ten year starting from the current year. For rural zones with DGR negative, the rate is maintained constant till current year. For rural zones with DGR higher than national mean, rate will decrease till achievement of national mean 20 years after the current year. This optimization also includes optimization of the capacity of garbage containers that depends on the size of agglomeration and the rate of production of SW. These actions are completed by other actions minimizing the impact of the process of collection on the environment. Focus should be made on

Table 2.6 Waste of obsolete pesticides and contaminated material by pesticides

Wastes	Quantités en tonne
Pesticides	765,066
Empty packages	369,165
Contaminated machines	1,184,649
Contaminated materials	556,870
Contaminated buildings	68,042
Contaminated soil	3,123,077
Veterinary products	1,538

the frequency of the collection, position of the containers should be in the intersection of different agglomerations, and the capacity removed in one go.

2.3.9 Waste of Obsolete Pesticides and POPs

Usage of pesticide has exceeded 19,000 cubic tons. Though regulations have been reinforced by the law 42–95, requesting authorization from official authorities for manufacturing and marketing pesticides in order to avoid miss usage, intoxications, and impact on the environment. However, during the eighties, Morocco has been subjected to repeated invasion by locusts, obliging authorities to use and purchase large amounts of pesticides, mainly organochlorines. Some of them remain as obsolete pesticides.

Surveys performed have revealed an amount of 756 CT, among which 20% stored at the owner companies, while the remaining 80% were stored in different public sites. Other wastes inventoried are presented in Table 2.6.

A joint program was launched by FAO (Food and Agriculture organization) and CropLife (a consortium of international companies involved in the marketing of pesticides). The program targeted the elimination of this category of waste and the estimation of the cost was evaluated to 886,000 for elimination of pesticide and cleaning water.

In addition to obsolete pesticides, persistent organic pesticides (POPs) have been subjected to ban according to Stockholm conventions. Morocco has launched its PNM (national plan of implementation of Stockholm convention). The first survey revealed the quantities presented in Table 2.7.

Based on this inventory, Morocco has made a plan to eliminate DDT. This has been achieved in Marseille in France in 2013. FAO has congratulated Morocco for his action.

Table 2.7 List of POPs inventoried in Morocco

POP	Quantity in kg	%
DDT	50,383,27	83,72
Chlordan	20,00	0,03
Dieldrin	181,00	0,30
Heptachlor	9,600,00	15,95
Total	60,184,27	100,00

2.3.10 Treatment of SW

Treatment of SW is mainly focused on hazardous waste. Only 8% is disposed, while the remaining is treated. A cooperation project between Morocco and Germany has targeted this issue by establishing CNEDS (National Hazardous Waste Treatment Center) to structure and improve the sector. The future National Hazardous Waste Treatment Center will provide Morocco with a better visibility of its hazardous waste stream in terms of quantity and content. It will also drastically improve the environmental management for collection, treatment, recycling, and disposal. Today, only 8% of industrial waste is disposed off through the private sector. The remaining 92% is handled by the informal sector or stored anarchically.

Due to the potentially high risks to human and environment, medical waste management is of major importance. Information on this issue is rare in Morocco. A case study of Souss-Massa region was reported. The authors surveyed seven of the twelve hospitals in the region, covering 66.2% of the bed capacity. Medical waste generation rate ranged from 0.4 to 0.7 kg/bed-day with an average of 0.53 kg/bed-day. Infectious and hazardous wastes represent about 30.5%. The remaining 69.5% was similar in properties to municipal wastes. The personnel in charge of the supervision of medical waste have very low knowledge on the properties and the risk related to their handling and separation (49.4% of correct answer). In general, practices in most surveyed hospitals did not comply with the principles stated in Moroccan legislation [15]. Actually, there is no proper hazardous waste treatment and disposal facility in Morocco. The central treatment and disposal facility project in preparation with German financing has an expected capacity of:

- Industrial hazardous waste: 100,000 tons annually;
- Medical hazardous waste: 7,500 tons annually (incineration).

Sterilization facilities are planned to be installed in all the major hospitals [11].

2.3.11 Valorization and Recycling

Solid waste today is increasingly defined as “new materials for technologies.” Waste has come to be regarded as a useful material, providing a potential source of income.

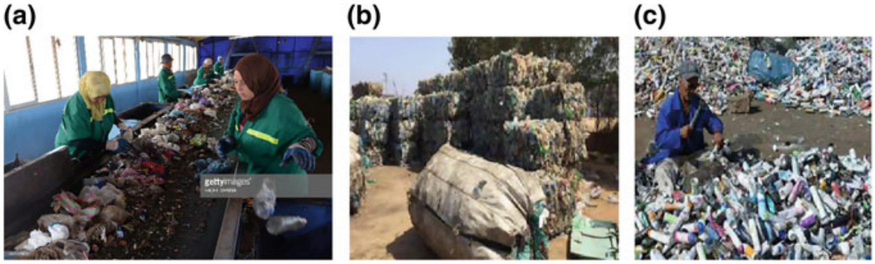

Fig. 2.5 Recycling of waste at Attawafoq cooperative (Oum Azza landfills)

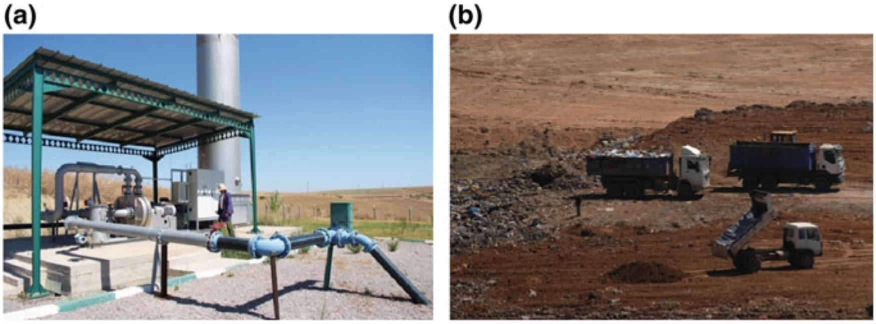

Fig. 2.6 Landfills of Fes and bioelectric center

The recycling market, for instance, is now an important industry generating revenues and jobs for many people in several countries. Increasingly, SW should be seen as a resource to exploit rather than as a problem to be dealt with. Valorization is an important step of the management of SW. This requires preselection and structure to convert the selected waste to the appropriate final product. Two experiences could be mentioned in this issue [11]:

- One experience of selection (landfill of Oum Azza—Rabat);
- Energetic conversion of biogas (Oujda and Fès).

The cooperative tends to be valorizing the waste collected and deposed in the site of Oum Azza near Rabat. Besides the contribution to reduce the impact of waste on environment, the negative image associated with the rubbish pickers named "Mikhala" in Moroccan dialect is changing, since they are enrolled as workers receiving a daily compensation (Fig. 2.5a–c).

In the city of Fes, the project of valorization of waste has led to the production of biogas used for lighting public streets. The central power produces 1,128 kW of electricity equivalent to 30% of the consumption by public street lighting. At its expected maximum capacity, the central will produce 5 MW (Fig. 2.6a, b).

2.3.12 Some Local Actions

Due to high rate of rural migration, urban zone has extended at a noncontrolled rate, difficult to control by the local authorities (communes). This has pushed the authorities to move to delegated management, generally ensured by private companies. These companies have to deal with the collection, deposit in landfills, and attempting selection. On another hand, a group of municipalities, called "Reseau Marocain pour la Gestion des Déchets Urbains (REMAGDU)" has been created to facilitate exchange of experiences and technical information. Each commune member is represented by one elected person and one technical staff. A technical report of different actions conducted by the members of the group has been published. (Cooperation allemande, GIZ, Royaume du maroc:Reseau Marocain pour la Gestion des Déchets Urbains) [11].

2.4 Institutional and Legislative Aspects

Degradation of the environment is a big concern for the authorities. It contributes to an economical loss of approximately 3.7% loss attributed to SW is about 0.5% of GNP. To meet the requirement of international and national trends and standards in terms of protection of environment and SW management, Morocco has adopted the concept of sustainable development and ratified several international conventions.

- Montreal protocol on Substances that Deplete the Ozone in 1992, the Vienna Convention and Amendments in London and Copenhagen in 1995;
- Convention on Climate Change in 1995 and the Kyoto Protocol in 2002;
- Basel Convention on transboundary movements of hazardous wastes in 1995;
- Stockholm convention on persistent organic pollutants (POPs);
- Protocol on the prevention of pollution of the Mediterranean Sea in 1999;
- Rotterdam Convention.

To achieve the goals targeted in terms of solid waste management, legislative and administrative reforms have been introduced. The main legislation acts related to environment and solid waste are:

- Dahir No. 1-06-153 of 22 November 2006 promulgating Law No. 28-00 relating to waste management and disposal;
- Decree No. 2-07-253 of 18 July 2008 on waste classification and determining the list of hazardous waste;
- Decree No. 2-09-139 of 21 May 2009 on the management of medical and pharmaceutical waste;
- Decree No. 2-09-284 of 8 December 2009 establishing the administrative procedures and technical requirements for landfills;
- Decree No. 2-08-243 of 17 March 2010 establishing the Committee on polychlorinated biphenyls (PCBs);

- Decree No. 2-09-538 of 22 March 2010 establishing the procedures for developing the National Hazardous Waste Management Plan;
- Decree No. 2-09-285 of 6 July 2010 Decree No. 2-09-285 of 6 July 2010 establishing the procedures for developing the prefectural or provincial master plan for the management of household and similar waste and the organization procedures for the public inquiry to this plan;
- Decree No. 2-09-683 of 6 July 2010 establishing the procedures for developing the regional waste management plan for industrial, nonhazardous medical and pharmaceutical, final, agricultural, and inert waste, as well as the organization and procedures for the public inquiry related to this plan.

2.4.1 Plastic Waste

Waste of plastic has received important consideration due to persistence of this material in the environment. The following legislation acts tend to reduce the impact of plastic waste on the environment:

- Law 22-10 dated 16 July 2010 prohibiting the manufacture and marketing of nondegradable bags;
- Decree 2817-10 of 19 April 2011 on criteria for the development of prefectural or provincial management of household waste and similar waste;
- Dahir 1-10-145 promulgating Law 22-10 on the use of degradable or biodegradable plastic bags, BO n° 5862 of 5 August 2010;
- Decree 2-11-98 of 17 June 2011 on enforcement of Law 22-10 on the use of degradable or biodegradable plastic bags;
- Decree 3167-11 of 4 November 2011 on the application of Article 2 of Decree 2-11-98 of 17 June 2011 on the application of Law 22-10 on the use of degradable or biodegradable plastic bags.

2.4.2 National Solid Waste Program (PNDM) 2008–2022

To cope with the challenges posed by the management of household and similar waste, the ministries involved in the environmental issue (interior, finance, and environment) jointly developed a National Solid Waste Program (PNDM) (see Table 2.8), which aims to upgrade the management of municipal solid waste by 2022. In 2012, revised objectives of this program were declared:

- Ensure the collection and cleaning of household waste to achieve a collection rate of 90% in 2020 and 100% in 2030;
- Ensure access to controlled landfills for household and similar waste for all urban centers (100%) by 2020;
- Rehabilitate or close all existing disposal sites (100%) by 2020;

Table 2.8 Situation of the implementation of PNMD till 2014 [11]

	2008	Present (2014)
Percentage of collected SW in urban zone	44%	85%
Percentage of collected SW in rural zone	n/d	n/d
Percentage of SW deposited in controlled landfill	10%	40.25%
Number of controlled landfills	01	19 in Fès, Oujda, El Jadida, Essaouira*, Rabat, Berkane, Figuig, Guelmim, Al Hoceima, Agadir, Nador, Dakhla, Mohammedia, Laayoune, Ifrane, Khouribga, Es Smara, Safi et Mdiq-Fnideq
Number of ongoing controlled landfills	/	06in Marrakech, Tanger, Khénifra, Casablanca, Ouarzazate et Meknès
Number of controlled landfill rehabilitated.es non	01	13 in progress 41 to be launched 52 planned by 2016
Regional plan for SW and pharmaceuticals	/	01 in Region of Taza Al Hoceima Taounate in progress
National plan of dangerous waste	/	

- Modernize the waste sector by increasing professionalism;
- Develop the sorting-recycling-recovery chain, with pilot sorting projects, to reach a recycling rate of 20% by 2020;
- Expand and implement solid waste master management plans for household and similar waste for all;
- Prefectures and provinces in the Kingdom;
- Train and raise awareness among all stakeholders.

2.5 Conclusions

Management of solid waste in Morocco is a new concept adopted by the authorities within a global strategy of protection of the environment. Actually, the growth of population variation of economical activities generates increasing wastes. This issue has risen public concern and has pushed Morocco, to adopt, environment act, adhesion and ratification of the main international conventions, instauration of administrative and legislative laws made Morocco in front line with the main challenges related to the protection of the environment. Among these challenges, SW management represents an important pillar of the national strategy based on the national program of solid waste management. The objectives include improvement of collection of wastes, built new controlled landfills, restore or close noncontrolled landfills, improve the treatment and valorization processes, encourage recycling, and improvement of the life of pickers in various landfills. At administrative and legislative levels, more coordination is needed between departments and services to improve the management in terms of collection, treatment, and valorization. On another hand, some social action should be engaged toward consumers to reduce their food waste mainly in Ramadan.

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Chapter 3
Waste Management in Tunisia—What Could the Past Bring to the Future?

Olfa Mahjoub, Amel Jemai and Imen Haddaoui

Abstract Waste production has tremendously changed in Tunisia following the transformation in the population's lifestyle. Wastes' quality has changed as well driven by the diversity of products and consumption trend. Government and local authorities started very early to overcome challenges associated with waste by setting strategies, action plans, and updated policies. Waste management has shown substantial progress since the 1990s and during the early years of 2000s. The institutional and regulatory frameworks of solid waste management have improved, likewise the business model in which both governmental and private sectors are involved as a public-private partnership (PPP). Solid wastes are collected and discharged into controlled landfills or are recycled. Since the majority is organic, recycling or energy and biogas production was promoted; the rest of waste is chiefly composed of paper and plastic materials that pose an environmental concern. Liquid waste consisting mainly of urban wastewater is relatively well managed with 98 % of effluents secondary treated. Nevertheless, more than 80% of the treated wastewater is released into the water bodies. Water Code, as the overreaching regulation on water, together with other national regulatory texts is revised and updated to protect the environment from all types of wastes. Actions plans are under development to promote recycling and reuse of wastewater in various domains. Liquid and solid wastes are both sources of nuisances and potentially hazardous contaminants that impact human health and cause irreversible transformation of the ecosystem if they are mismanaged and/or improperly discharged. In this regard, various types of micropollutants released to water bodies or infiltrated from landfills, as a whole, were identified like pharmaceutical compounds and industrial compounds. Despite the multiple initiatives undertaken in the framework of national and international programs, waste management sector is facing several obstacles to be urgently addressed. The low level of collaboration between national institutions and local authorities and prevailing overlapping roles, the low involvement of the civil society, and the lack of funding, in addition to the difficulties in adopting/applying new technologies and changing citizens' mindset and

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attitude are among the main hurdles. Since the year 2011, solid and liquid waste management in urban and rural areas has witnessed a remarkable degradation. Several weaknesses linked to the institutional, financial, and regulatory levels were reported, exacerbated by the closing of several landfills. The latter is motivated by citizens' motions. To counterbalance the irreversible impacts of waste discharge on health and environment, a number of programs are currently developed under the umbrella of the new decentralized decision-making policy. Municipalities are expected to leverage local efforts for scaling up successful initiatives for sustainable and integrated waste management.

Keywords Waste management · Strategy · Pollution · Sustainable · Integrated · Environment

3.1 Introduction

The population has increased in both urban and rural areas resulting in an increase in waste production at a higher pace, particularly in urbanized areas. In 1900, 13% of Tunisia's population was living in urban areas. A century later, the percentage increased up to about 49%. The volume of waste has exponentially increased from 300,000 tons to more than 3 million tons of solid waste per day. By 2025, waste production is expected to double worldwide. The Organisation for Economic Co-operation and Development (OECD) countries are the largest producers, accounting for about 44% of the world's waste. A slow decline is expected by 2050 driven by advances in material science and technology. In the MENA region, average waste generation per capita per day is around 1.1 kg (half of the average in OECD countries). The "business-as-usual" projections estimate that by 2100, solid waste generation rates in those countries will exceed 11 million tons per day, more than three times the current rate. Without solid actions, this striking by-product of civilization will result in serious damages to the climate and environment [25].

Efficient waste management is a challenge worldwide. Many countries have observed a paradigm shift in their waste management policies orienting them toward recycling, energy harvesting, and the improvement of treatment and disposal methods/techniques, thereby considering waste was a recyclable source. In some countries of the European Union, the amount of waste has decreased from 527 kg/person/year in 2002 to 475 kg/person in 2014, which is 10% lower. This decrease was promoted by various public initiatives undertaken since 2007. Consequently, waste contribution to greenhouses gases (GHG) emissions has also decreased by about 35% (from 223.6 in 2002 to 144.4 million CO_2 equivalent in 2014) during the same period. The percentage has decreased in 2015 [18]. Thanks to a more rigorous management strategy with the future emission targets of 375 Mt CO_2 set for the year 2040, the total CO_2 emission has declined by about 339 million tons of CO_2eq during the period 1990–2014, of which 55 million tons were ascribed to waste management measures. Meanwhile, in developing countries, GHGs from waste are four times higher, estimated at 12%. Nevertheless, the EU waste prevention plan seems to ignore the drivers of waste generation, such as consumption, relying on conventional waste management goals, with the aim of preventing the generation of waste at the source [26].

By the year 2020, the European countries are expected to comply with the European Union solid waste management directives and standards including the application of waste sorting at a larger scale, valorizing at least 50% of domestic wastes, 70% of the building wastes, discharge less than 35% of their biodegradable wastes, and recycling at least 55% of the packaging wastes. Putting in place the adequate infrastructure for an environmentally sound waste management and developing waste management plans are also a priority. Consequently, many countries of the Euro-Mediterranean region were pushed toward incorporating this framework in their regulations and national strategies. North African countries are producing about 250 kg/person/year, which is 50% less than the European ones [14].

At the Mediterranean level, about 50% of domestic wastes are biodegradable. Countries are producing relatively comparable quantities of wastes ranging between 0.7 and 1 kg/inhabitant/day in urban areas and between 0.3 and 0.6 kg/inhabitant/day in the rural area. Jordan has the highest amounts of waste produced in both urban and rural areas together with Egypt for the urban area and Algeria in the rural area. Tunisia was producing 183 kg/person/day of municipal solid waste in 2004. An increase was observed in 2014 up to 292/person/day, which is 60% more [14].

Though, the country has more than 30 years of experience in waste management with a number of institutions and departments to support the governmental effort in this regards. Regulatory, technical, institutional, and economic aspects in addition to transport, treatment, elimination, sorting, and valorization/recycling of various materials were addressed [14]. The Communities Organic Law was a milestone in waste management history in Tunisia. It contributed to the progress of the sector and has pushed forward the achievements of crucial steps like the establishment of the National Program for Solid Waste Management (PRONADGES) in the 1990s, the promulgation of the framework law on waste management in 1996, and the creation of a dedicated institution, i.e., the National Agency for Waste Management (ANGed) in 2005 [2].

Studies and programs have covered the establishment of decision support tools in domestic waste management to help developing adapted alternative treatment processes to dumping in landfills [23].

In Tunisia, municipal waste is increasingly perceived as a threat to the coasts and the striving tourism industry. The Tunisian governmental institutions are supported by various international organizations like the World Bank which has supported the rehabilitation of harmful landfills to help it "enter the emerging global market of carbon credits through the Clean Development Mechanism (CDM) introduced under the Kyoto Protocol" [41].

During the last two decades, waste management has witnessed progress in raising awareness on the impacts of wastes on the environment that has become increasingly prominent. Nevertheless, the sector is still inefficient due to the various obstacles that are encountered at various levels. Lack of communication between the actors, lack of capitalization of experiences including successes/failures, limited involvement and low motivation of NGOs, lack of impactful sensitization campaigns among the population, poor enforcement of the existing laws, lack of R&D projects to address the sector priorities, etc., are hampering the sector from achieving the objectives set during national actions and strategies [2].

After 2011, several studies have been commissioned within large programs funded by international governmental and non-governmental organizations for promoting and supporting the country's efforts toward sustainable waste management. Detailed reports have been published to deal with miscellaneous aspects related to the status, strengths and weaknesses, perspectives, and opportunities of waste management. Nonetheless, the country is undergoing a *status quo* situation characterized by a multitude of opportunities offering large international investments opposed to low awareness of the population overwhelmed by the economic and social decline.

This chapter is meant to be a critical review to showcase lessons learned, the current status of waste management in Tunisia, and related future challenges. It aims at highlighting strategies, initiatives, and programs undertaken for the sustainable management of waste and to shed light on the institutional and regulatory frameworks together with other aspects like financial incentives put in place to enhance environmental protection and to mitigate impacts of waste discharge. Thereby, the occurrence of micropollutants in waste is briefly described by citing relevant examples. Innovative approaches adopted to raise dwellers' awareness and the role played by the civil society are also discussed.

3.2 General Insight into Waste Management

"Waste is any type of residue emanating from the use or transformational production systems, and any kind of substance, material or product that has no use and are readily to be disposed of." This is the definition of waste according to the first article of the Tunisian Law promulgated on July 15, 1975.

The first studies on solid waste management started in the 1980s. One of the most important was carried out on the Greater Tunis and metropolitan area in 1985. However, the study's outcomes and developed activities were not implemented immediately. It was decided to wait until the launching the "Ministry of Environment" in 1991 and the Department of Solid Wastes set within the National Sanitation Utility (ONAS). Later on, solid waste management was mandated to the National Agency for Environmental Protection (ANPE). In 2005, the government launched the National Agency for Waste Management (ANGed) in recognition of the importance and the need to consolidated waste management system following the growth in the various sectors in the country [14].

In the 1990s, Tunisia has developed a National Environmental Action Plan which provided a general framework for launching a significant environmental and resource conservation programs. In 1995, a framework law on waste management was promulgated [41]. Later on, several projects and programs were initiated for environmental protection against pollution and targeting a substantial improvement of the quality of life [27]. Waste management was set up within the general framework of the law governing municipalities (The Communities Organic Law). It has witnessed several developments and went through three main stages:

– Establishment of the PRONADGES in the 1990s together with the promulgation of laws and decrees. Many studies including waste sorting and management, composting, participation of the private sector, and others were executed during that period.
– Passing the national framework law on waste control and management, in 1996, to support the implementation of the "polluter pays" principle.
– In the 2000s, waste management was among the national priorities for which the government has dedicated a Restricted Ministerial Assembly to take provisions for and to develop a set of recommendations in this regard. Since January 2000, several programs were launched to put PRONADGES into practice. Many waste-burying sites and controlled landfills, and transfer centers were established; Jebel Chekir as the very first controlled landfill established in Tunisia in 1999 to solve major problems encountered during the era of uncontrolled landfills.
– Establishment of ANGed in 2005 and the launching of the National Program for Integrated and Sustainable Waste Management (PRONGIDD) [27].
– PRONADGES establishment was accompanied by an agreement signed between the Ministry of Interior (in charge of local communities) and the Ministry of Environment, represented by ANPE and then ANGed. According to this agreement, the local committees were in charge of planning, program implementation, and exploitation of the infrastructures related to domestic waste management [27].

Despite the efforts deployed by the government to set an efficient mechanism for the management of solid and liquid wastes, several problems and gaps were identified suppressing the country from achieving substantial progress in this field. In the middle of the year 2000, it was estimated that about 40% of total municipal wastes were disposed of insanitary landfills and around two-thirds of Tunisia's urban population had to cope with about 400 uncontrolled dumpsites. The latter has become a real threat to the environment and public health and was supposed to be replaced by controlled landfills [15, 41].

After January 2011, during the post-revolution phase, solid waste management has observed a huge decline caused by several social claims and oppositions to the current way of managing the transfer centers and the landfills. The management practices for waste collection and disposal are deemed to be inefficient in urban and rural areas, resulting in serious wholesomeness related problems (Fig. 3.1). Public services put in place by the municipalities in charge of waste collection, treatment, and disposal have become costly in addition to being inappropriate, thus leading to serious environmental damages [14].

Fig. 3.1 Open dumping site observed on Melian stream banks. *Source* Courtesy of Olfa Mahjoub (2013)

3.2.1 Facts and Figures

Urban wastes are causing high risk to the environment because of their composition, on one hand, and the increasing volume following population's growth and the change in lifestyle, on the other hand [8].

In 2004, urban domestic waste production was estimated to be around 1.732 million tons/year) and was expected to reach 3.270 tons/year in 2019, while in 2013 the annual amount of municipal waste produced annually was already reached around 2–3.5 million tons with only 1 million of recyclable waste. The total amount of waste discharged in 10 landfills and 50 transfer plants in a total of 120 municipalities was about 1.6 million tons per year. These figures indicate that wastes are not totally eliminated; only 50% goes to controlled and uncontrolled landfills. For instance, in the Greater Tunis, Jbel Chakir landfill receives between 2,000 and 2,200 tons of municipal waste per day (about 500,000 tons/year) [37].

A large sampling campaign carried out in the Greater Tunis and metropolitan area in 2005 showed that municipal wastes in urban and peri-urban are mainly composed of biodegradable organic wastes (42–69%), paper/cardboard (8–32%), plastic (7–13%), textile (3–8%), metal (1–4%), glass (0–2%), and various other material (6–12%) [13]. More generally, the biodegradable materials represent 68% of municipal wastes; the rest is composed of plastics (11%), paper/cardboard (10%), and a mix of metal, glass, textile, and various other materials. This composition was repeatedly mentioned in almost all the reports related to waste management published by ANGed, ANPE, and other organizations during more than ten years. This shows that either waste composition did not change over time or that data are not updated, which is more likely. Wastes are for 65% made of water; the high moisture content is problematic with regard to waste distribution and represents the main obstacle to an adequate further transformation; the remaining 35% is made of organic and inert material [4].

The average composition of domestic wastes addressed by ANPE considers the following materials:

1. Organic/biodegradable wastes (**68%**): This fraction is composed of wastes produced in gardens and kitchens like food wastes, tree branches, grass, etc.
2. Paper and cardboard (**10%**) include newspapers, journals, books, and notebooks disposed of from households and administrations, and packaging processes.
3. Plastic, leather, rubber (**13%**): This fraction is composed of plastic materials like PVC, PE, PP, and polystyrene.
4. Metal waste (**4%**) are composed of scarps, cans, and broken equipment of water and electricity installations. Heavy metals like zinc, copper, led, mercury, and cadmium are present in batteries, newspapers, and plastic as coloring dyes. These are very toxic components and very problematic to the environment.
5. Textile (**2%**) is composed of clothes, fabrics, carpets, etc.
6. Glass and ceramics are composed of broken bottles and glass [8].

Other fractions may be considered, rather used as indicators; this is the case of the following:

– Volatile organic wastes which are unidentified waste representing about 2.5%.
– Total biodegradable waste is an indicator representing the compostable fraction estimated at 84.5%. Nevertheless, as 50% of the papers/cardboards are collected by private companies and do not end up landfills, the compostable portion does represent only 79%.
– The total volatile fraction is corresponds to the biodegradable fraction; together with the plastic fraction, they represent 91.5% of waste [8].

In the year 2002, the quantity of domestic waste produced in urban area was about 0.500 kg per person per day (1.700 million tons/year). Paper wastes were estimated at 1.305 million tons/year, and medical wastes were around 15,000 tons/year. In 2012, the amount of domestic waste has increased. Dwellers in urban area have produced about 0.800 kg of wastes per person per day, which is 60% more compared to 2002. In counterpart, only 0.150 kg was produced in the rural area during the same year, which makes a total of about 2.425 million tons of wastes per year. In addition to domestic waste, there are around 150,000 tons of industrial, 60,000 tons of paper/cardboard, and 18,000 tons of medical wastes [27].

Apart from that, a relatively steady quantity of phosphogypsum is discharged in the environment estimated to an average of 5,000 tons/year [20, 27]. Once produced, all these wastes find their way to landfills; 70% goes to controlled landfills, 21% to uncontrolled landfills, whereas only a small portion is composted (5%) and recycled (4%) [14]. Few internationally funded project implemented at regional has promoted composting (Box 1).

Box 1

Sfax is one of the largest and important economic spots in southern Tunisia. Its daily production of domestic waste is about 500 tons. This city has one controlled landfill and 7 transfer centers covering 13 urban areas with a capacity of 210,000 tons. In Sfax, solid wastes are sorted into different classes: domestic wastes (that undergo sorting process), biodegradable wastes disposed of by wholesales markets, green wastes, agro-food industrial wastes, poultry farming wastes, manure from farm breeding, biosolids from wastewater treatment plants, liquid and thick olive mills, fishery wastes, and slaughterhouse wastes. MED-3R, an EU-funded project, contributed to the installation of a sorting plant for urban wastes and the purchase of various equipments for the composting process. According to circular economy principle, the project has provided fertilizing material to grow various crops like fruits trees, forages, and garden crops.

Source: Zouari [44].

3.2.2 Classification of Solid Waste

3.2.2.1 Municipal Waste

Urban wastes include domestic and similar wastes and green wastes produced from green areas or in reselling markets [27].

Domestic wastes undergo several steps before reaching the landfill (Fig. 3.2). Collection is done by the municipalities which may outsource this operation. No selective sorting is applied at the household level. Therefore, an additional sorting step is necessary after collection and transfer; this step is carried out in the sorting plant. Waste transfer and elimination are the tasks of ANGed that may engage the private sector [14]. The total quantity of domestic and similar wastes was estimated at 2.025 million tons/year in 2004, forecasted to reach 3.756 million tons/year in 2019.

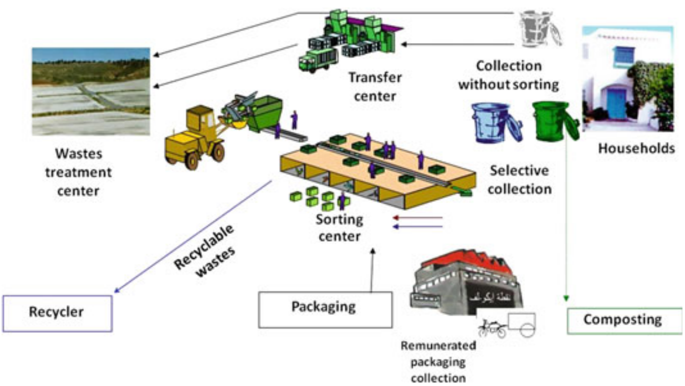

Fig. 3.2 General pathway of domestic waste from collection to disposal

Green Waste

Based on figures published by ANPE in 2003, about 80% of the total produced vegetable crops are commercialized in public markets. The majority of the leafy vegetables are sold with their leaves. Only a portion of these wastes is dumped in landfills because they may contain other types of waste. Farmers of peri-urban areas may use these wastes as animal feed. A large part of these green wastes is removed by shopkeepers on-site or by the consumers, while the rest is left in the markets and shops to be collected by the municipal services during the cleaning operation. In some renowned large weekly markets, like Sidi Bahri and Ariana, green wastes may represent between 5 (lettuce) and 30% (carrots and fennels) of the commercialized products [7] which is a large amount that requires appropriate intervention.

Taking into account the total quantity of vegetables sold in the markets per year across the country, green wastes may represent up to 50%; rotten products like watermelons, melon, and tomatoes occurring especially during the summer season may represent an additional 5%, which makes a total of 55% of green wastes [37].

Wastes produced in wholesale markets do not require tedious sorting operations which make them potential material for compost production. Meanwhile, the large volume of green wastes is also resulting from the inadequate/absence of sorting and calibration prior to commercialization. Based on population growth and consumption forecasted increase, the quantity of green wastes is estimated to reach up to 19,849 tons/year in 2019, while the quantity was about 18,729 t/year in 2014 (ANGed 2009). Green wastes from parks are estimated at 33,000 tons [37].

Biodegradable/Organic Waste

Domestic wastes are mainly made of biodegradable material. The quantity was expected to double by 2020 compared to the prevailing situation in 2009 (ANGed 2009). The government considers the valorization of biodegradable wastes (biomass) a driver to a green economy, as it contributes to environmental protection, jobs creation, and generation of incomes, advancing and developing innovative technologies, and represents a source of renewable energy; an asset for the economy [4]. Biodegradable wastes were composed of:

- 2.2 million tons of domestic wastes corresponding to 0.600 kg/person/day.
- 2 million tons of agricultural wastes.
- 800,000 tons of olive mills out of which 263,000 tons are produced in Sfax and other coastal cities like Sousse, Monastir, and Mahdia with a total production of 214,000 tons.
- 400,000 tons of poultry dung among which more than 160,000 tons are produced in Sfax, which is considered the greatest potential for energy production, estimated at 7100 kW; Nabeul together with Tunis and its metropolitan area are generating around 125,000 tons and 100,000 tons, respectively, with a potential of 5900 kW for both cities.

– 2 million tons of liquid sewage sludge among which only 350,000 tons are transformed through biomethanization process [4].

In 2010, the evaluation of the existing potential for recycling biodegradable organic wastes revealed that around 500 million m^3/year of biogas could be produced with an energetic potential of 3 million Mega Watt hour/year [4].

Used oils and grease are also important sources of waste. During the year 2000, the total produced quantities were estimated at 80,000 tons/year among which 50,000 tons were produced in public premises like restaurants and hotels; the rest was generated by households. Tunis, Nabeul, Sousse, Sfax, and Médenine, including Jerba and Zarzis, were on the top list of producers [6]. In 2018, ANGed has commissioned a study for updating the management plan for this type of waste including the supply of special containers nearby large communities to collect used oil from houses.

Biodegradable/organic wastes may undergo two types of transformation processes:

1. Biomethanization, through anaerobic digestion for energy production, is one of the objectives pursued by the government while promoting the use of renewable energy. The government also launched a framework of an action plan aiming at reaching 3% of the required energy from renewable resources in 2010. However, the achieved percentage was limited to 0.3% despite the initiatives launched since 2001 (ANGed 2009). One of the large projects was installed in 2010 in the Bir Kassaa wholesale market producing 25 tons of organic waste per day. Together with municipal wastes (20 tons/day) and wastes from restaurants (2.5 tons/day), all were supposed to be transformed through biomethanization to produce around 3000 m^3 of methane and 45 tons of fertilizing material [4].
2. Composting for agricultural use is a worthwhile option driven by the high demand for organic matter used as soil fertilizer. In fact, the quantity of manure produced in livestock farming was proved to be insufficient to improve arable soil quality because of their very low organic matter content (1%) in most parts of the country. Therefore, using biodegradable wastes derived compost would be highly beneficial because, on the one hand, it reduces the discharge of wastes in controlled dumpsites, and on the other hand, it allows soil quality improvement (ANGed 2009).

Recycling of organic waste was assumed to be promoted as the cornerstone of the organic waste management strategy in Tunisia. The very first experience in this regard started in 1991 and was interrupted in 1998. The developed strategic plan in 2006 was hardly implemented and currently. Currently, only three units are operating to deliver a commercial organic matter product [14]. Despite the existing potential and the need for organic matter and energy production, the efforts were far below expectations and insufficient to fulfill the required quantities. Therefore, the sector is deemed to be still on the learning curve to develop strategic approach to advance the sustainable waste management at the national level (ANGed 2009).

Plastic Wastes

Plastic manufacturing is the main source of plastic environmental pollution. More specifically, it is the massive use of plastic bags that is incriminated for the widespread of plastic waste in the environment. Plastic waste production is estimated at 10,000 tons every year and represents about 11% of the total produced wastes in the country. Since the early year 2000, plastic waste management has become one of the national priorities assigned to ANPE through the initiative "Eco-Lef" launched in 1997. "Eco-Lef" system supports take-back actions and valorization of used plastic packaging in addition to rationalizing the use of plastics and sensitizing the population and the different actors.

Public packaging recovery and reuse system require that every producer and distributor are selling bags or packaged product to organize the recuperation of the used bags and packaging. Plastic waste collected per year represents a total of 55.000 tons among which 12.000 tons are collected by Eco-Lef system [37]. This initiative was based on voluntary actions and allowed the distribution of 470 containers for waste collection in areas renowned for their high plastic consumption. The system Eco-Lef includes all the operations starting from collection to recycling including sorting. As an example, plastic bottles are collected by low-income people to be delivered to large centers for recycling. Consequently, around 400 private companies were created for collecting, transporting, and recycling plastic. Plastic waste remunerated collection was launched, and it is still working nowadays [37].

Paper, Glass, Textile

A total of 44,000 tons of paper and cardboard and 100 tons of food cartons are collected every year. Paper and cardboard recycling is still on the learning curve though offering 5,000 jobs throughout the country. A small informal sector for recovering food waste bricks is currently being set in place. For the moment, there is no industry set up for liquid food packaging [37].

Biosolids

In 2016, Tunisia has 115 operational treatment plants among which 107 were treating urban effluents, thus producing around 255 million m^3 of secondary treated wastewater and 175 m^3/year of dry biosolids/year including 55,000 m^3 naturally bed-dried and 120,000 mechanically dried. In 2017, about 29,000 tons of biosolids dried on beds produced in 12 WWTPs were valorized in agriculture by spreading over 400 ha of land, thus involving about 23 farmers. In total, only 25 WWTPs were valorizing their produced biosolids. The initiative started in 2012 with 941 tons of biosolids spread on 93 ha of agricultural land. The maximum amount was reached in 2016 with 6950 tons spread over 697 ha [33, 34].

Biosolids produced in wastewater treatment plants can serve as fertilizer for agricultural use, either directly or after compositing as they contain 30–35% of organic matter, around 1.2–3% of nitrogen, and 0.33–1.34% of phosphorous. This practice was widely spread before its ban in 1998 due to microbiological contamination. This action resulted in the discharge of biosolids in landfills causing a crucial environmental problem. Otherwise, biosolids were also disposed of in the WWTPs surrounding areas causing discomfort due to bad smells and development of insects. The National Tunisian Standards for the use of biosolids in agriculture NT 106.20 (2002) established in 2002 came to regulate the use in agriculture by setting minimum quality criteria for spreading on agricultural land. However, this was not enough to overcome the existing hurdles. In 2011, ONAS and ANGed signed a joint framework agreement allowing biosolids produced by ONAS in WWTPs to be buried in controlled landfills together with domestic and similar wastes [32].

In 2014, ONAS commissioned a study covering the Greater Tunis and metropolitan area for prospecting potential solutions to biosolid management by the year 2035. Three scenarios were considered: a green line for use in the agricultural sector through composting or direct spreading on agricultural lands; a red line for industrial use like producing concrete or incineration; and a black line for direct dumping in landfills together with municipal wastes [32]. Further, an agreement was concluded in 2017 between ONAS and the Tunisian Union for Agriculture and Fishery (UTAP), supported by the MARHP to promote environmentally sound and sustainable use of biosolids in agriculture, in addition to the reuse of treated wastewater [34].

Apart from this, ONAS and SONEDE (water supply utility) had a very ambitious plan to contribute to the national plan for sustainable development and better management of their energy consumption. Accordingly, these two institutions planned to use biosolids for energy production through methanization [34].

E-waste

Around 90,000 tons of e-wastes are deposited each year out of which only 22,500 tons are collected, which represents only 25%. Six processing units having a capacity of 18,500 tons/year were installed; a new one with a capacity of 24,000 tons/year was supposed to start in 2014 [37].

3.2.2.2 Industrial Wastes

The flourishing industrial sector has contributed substantially to the increase in the volume of industrial wastes. These are usually discharged in uncontrolled landfills resulting in hazardous impacts on the environment. During the period 2004–2009, a national program was put in place aiming at reducing the discharge of industrial wastes and closing all uncontrolled landfills together with the installation of a treatment plant in Jradou area, north of the country. Three wastes storage and transformation centers were installed in the north, the center, and the south part of the country [8].

Industrial wastes are classified into three main categories:

(i) Hazardous industrial wastes or generated from polluting processes;
(ii) Industrial wastes assimilated to domestic wastes;
(iii) Domestic wastes produced in offices and other premises or inert wastes.

The last two categories represent 80% of the industrial wastes and are estimated at 1.5 kg/person/day. The quantity of non-hazardous industrial wastes was estimated at 116,000 tons/year [37]. The volume of industrial wastes is calculated based on the number of employees in a given industrial unit and the specific production of 1.2–2 kg/employee/day. Accordingly, the amount of wastes is proportional to the number of jobs in the industrial sector. In 2004, about 805 tons/day were produced, expected to reach 1083 tons/day in 2019 [8]. The Groups of Maintenance and Management (GMG) are in charge of collection and transportation of non-hazardous wastes in industrial areas. In 2010, non-hazardous wastes were transported to 10 landfills; they are controlled by the private sector [37].

Hazardous waste production is estimated at 150.000 tons/year; around 12.000 tons were collected and processed in the center of Jradou in 2010. Hazardous wastes are treated in 4 units with a capacity of 90.000 tons/year. Only Sfax and Gabes centers were ready for operation; the center of Jradou was pending due to social protests [37]. An additional average quantity of more than 5 million tons per year is produced as phosphogypsum. Phosphogypsum is the by-product of phosphates industry consisting in phosphate rock processing for fertilizer production. Worldwide around 280 million tons/year are produced. This by-product is mostly disposed of without any treatment, usually by dumping in large stockpiles [24]. In Tunisia, phosphogypsum is classified as hazardous waste produced and managed by the Tunisian Chemical Group [11]. ANGed is in charge of the operation of infrastructure and facilities dedicated to the treatment of industrial and hazardous waste [37].

3.3 Micropollutants in Wastes

The occurrence of micropollutants in wastes and their release can only be addressed through scientific research work which can provide proofs of the potential harm they can cause to the environment. This is challenging because it depends largely on the availability of published results. Therefore, this paragraph is far from being an exhaustive review of research outcomes on the presence of micropollutants in liquid and on solid wastes in Tunisia. It is rather meant to give an insight on the type of micropollutants that can be released by mismanaged liquid and solid wastes in the environment.

Before addressing the presence of micropollutants in liquid and solid wastes, the differences and/or similarities between emerging contaminants and micropollutants are worth explanation. Years ago, many contaminants were not possible to detect in the environment because of the analytical barriers. Thanks to the availability of advanced analytical tools, many compounds were identified and quantified in environmental matrices. These compounds are called "emerging contaminants" because of this property, among others, of being recently detected. This is the case of pharmaceutical compounds and personal care products and their metabolites. Generally, emerging contaminants are chemicals present in the aquatic environment in the nanograms to micrograms per liter range or even low. Because of the concentration range, they are often called organic micropollutants too. Many of these have been and are currently undetected. As most of the chemicals end up in sewage, "emerging contaminants" describes more often the pollution of the aquatic environment [29].

In Tunisia, it is estimated that about 20% of solid wastes end up in the environment causing pollution of the receiving watercourses. However, the term "Waste" does not always refer to "pollution"; these are two different terms. By definition, wastes can be either good or bad material. Meanwhile, pollution is expected to have no positive effect. Therefore, waste may be or not a source of pollutants/contaminants to the environment; all depend on the way they are managed [29].

Waste management should take into consideration several aspects in order to reduce the impact of micropollutants on the environment. Treatment may not always be recommended as the best solution to get rid of these contaminants because treatment of solid and liquid waste has some limitations. The latter are mainly related to the type of compound to be removed. From a technological point of view, the to-date advanced technology may not work for what would be "new compounds" and the type of applied technology depends on compounds characteristics and persistence. Besides, treatment by-products may be more harmful than parent compounds, thus exhibiting mutagenic and/or toxic potential. Economically speaking, treatment and efficiency should be balanced against cost because, for instance, the longer hydraulic retention time of effluents in WWTP may not be more efficient for all compounds, while it may be costly. Also, advanced treatment processes depend on high energy input and a minimum water flow and may not be possible/affordable in developing countries due to energy cost [29].

According to the above waste description and classification, hazardous wastes are of high concern to the environment and to human health. Around 150,000 tons are produced annually. Hazardous wastes are defined by law and are listed in Appendix I of the decree No 2339 of October 2000 with all types of compounds requiring special management clearly referenced [2].

Liquid hazardous waste may be the most threatening to health and the environment because they may spread rapidly into water resources causing point source and non-point source pollution. They include effluents of industries, fertilizers, pesticides solutions, leachates from landfills, urban runoff, etc. One liter of wastewater can pollute eight liters of freshwater illustrating the extent of liquid waste impact on natural water resources. Generally, surface water is more prone to pollution. However, it can be more easily replenished because of dilution and rainfall. In counterpart, groundwater is more vulnerable to contaminants because once introduced into the aquifer they can be hardly removed/degraded.

Wastewaters and leachates are the main anthropogenic liquid wastes released in the receiving environment. For example, in Tunisia, out of the 80,000 tons of oil waste, 35,800 tons are released into the sewage network [6]. Therefore, the occurrence of micropollutants in wastewater and leachates will be addressed in the following.

3.3.1 Wastewater

Wastewater is worldwide renowned as the main source of emerging pollutants to water resources and the environment as a whole. Since the early 2000s, there has been growing interest in investigating the presence of micropollutants and emerging contaminants in environmental matrices. Published scientific papers were mainly focused on specific topics like the occurrence in wastewaters and treatment using various materials; some fields are still not well documented due to limited interest.

Currently, Tunisia has 119 wastewater treatment plants (WWTPs) distributed across the country with 110 WWTPs in urban area mainly located in coastal cities to protect the coastline from liquid discharges and preserve the marine environment; 8 WWTPs in rural area; and one for industrial effluents. These WWTPs are producing around 330 million m^3 per year of secondary treated effluents. Medium and low organic load activated sludge processes represent more than 80% of the existing treatment processes. About 3% of the raw wastewater is discharged in the receiving water [35].

Influents and effluents were characterized at the WWTP to evaluate the treatment efficiency in eliminating some chemical compounds. However, studies are restricted to few WWTPs and depend on the uses/discharge of the effluents and the potential burden to the environment and the ecological system. Studies on compounds that could be potentially considered as tracers of contamination are rarely reported. Examples are described in the following to displaying categories of micropollutants detected in effluents and their potential hazardous impact on water resources quality.

The analysis of urban and industrial effluent discharges on the seawater in the region of Gabes, southeast of the country, showed the presence of several organic compounds like hydrocarbons, including polycyclic aromatic and non-aromatic compounds. Registered concentrations were up to 270 mg/L. In Sfax Harbor, the concentrations of hydrocarbons were exceeding the standard limit of 1 mg/L recommended by the national guidelines for discharge in the receiving environment. This contamination could derive from small harbors, fishing communities, and small villages. Wastes were also found to be discharged directly into the sea without any adequate treatment [43].

Endocrine disrupters are emerging contaminants, and they encompass several types of molecules. These were investigated in the main streams of the country, Wadi Melian, which is receiving effluents from nearby industries and WWTPs. Biological tools using cultivated cells were used to assess the disrupting potential of the water stream. Heavily polluted effluents produced by food industries, like dairy products and cheese units, sugar manufacture, yeast manufacture, municipal slaughterhouses,

Fig. 3.3 Liquid and solid wastes discharged into water bodies and dumped into the soil. Courtesy of Olfa Mahjoub (2013)

and cereal manufacturing in addition to disposal of raw and treated wastewater, were the main sources. Endocrine disrupters may also be introduced into surface water through pesticide application on crops cultivated in agricultural land [19]. Fries at al. [21] have detected several pharmaceuticals, personal care products, and industrial compounds in surface water collected from Melian stream. Since 2011, Melian stream has become an open dumpsite where a variety of liquid and solid wastes are discharged (Fig. 3.3).

Hazardous industrial pollutants may also find their way in water resources, more often as illegal discharge. Investigation in 2015 showed that seven polychlorinated biphenyls (PCBs) and nine chlorinated pesticides were detected in Bizerte Lagoon, north of the country. DDTs, heptachlor, and endrin were the most detected compounds with a total concentration ranging between 0.42 and 14.92 ng/L. The high contamination registered in the southern part of the lagoon was likely caused by agricultural water drainage in nearby areas. On the contrary, high contamination with PCBs was registered in the northern part of the lagoon with concentrations ranging between 3 and 10.4 ng/L with a predominance of PCB 28 and PCB 52 congeners; these are often used in industrial activities [31]. During recent research, Medjerda stream, effluents from five WWTPs discharging into this stream, and industrials effluents from milk factories, slaughterhouses, sugar company, and tomato factory located close to the stream were analyzed for siloxanes, aliphatic hydrocarbons (alkanes), esters, polycyclic aromatic hydrocarbons, phthalate, and alkaloids. All the compounds were detected in TWW, industrial water, and surface water samples. The cytotoxicity and the occurrence of these micropollutants were strongly correlated [19].

3.3.2 Leachate

Leachate is the liquid that passes through a landfill, thus extracting dissolved and suspended matter from wastes. Leachate results from precipitation entering the landfill and moisture that exists in the waste when it is composed. It represents a major problem for municipal solid waste dumpsites and is significant threat to surface water and groundwater [35]. Leachate may contain not only dissolved organic matters but also inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, iron, sulfates, chlorides, and heavy metals like cadmium, chromium, copper, lead, zinc, nickel; and xenophobic organic substances [28]. Consequently, the environmental impacts of landfills depend on several factors including waste composition, technical barriers, landfill operation, and climatic conditions [21].

Leachate composition, treatment, and recycling were studied by several research teams in Tunisia coming out with numerous results covering their characterization, treatment, and impacts on natural resources.

In Tunisia, Jebel Chakir, one of the largest controlled municipal waste landfill in the Greater Tunis and metropolitan area (includes the governorates of Tunis, Manouba, Ariana, and Ben Arous), was established to reduce the impact of solid wastes. The site covers 120 ha. It receives about 1800 tons of waste/day from Tunis City and is generating about 200–250 m^3/day of leachates. Today, between 2,700 and 3,000 tons of waste reaches the landfill daily, carried on trucks [17]. The high moisture content of solid wastes was shown to produce leachate containing a large organic fraction. The presence of high biodegradable fraction implies that biological treatment process can be easily applied [15].

In Bizerte, north of the country, landfill leachates were analyzed for micropollutant compounds including phenols, polycyclic aromatic hydrocarbons, aromatic acids, aliphatic acids, esters, alcohols, and phthalates ester. The evaporation pond showed the presence of 12 predominant compounds including acids and phenols. These compounds are potential sources of contamination to water resources in the region after percolation through the soil when waste disposal is practiced without proper treatment [38].

The analysis of leachate revealed the presence of a high load of organic matter, ammonia, salts, phenols, and hydrocarbons. Concentrations were reported to exceed the Tunisian National Standards of discharge in the receiving waters. Leachate was found to be toxic, even after treatment with membrane bioreactor [1, 10]. Similar studies on leachates analyzed before, during, and after treatment with anaerobic membrane bioreactor showed the effectiveness of the treatment in removing a large number of compounds like benzoic acid, trimethylsilyl ester; cyclohexane carboxylic acid; heptanoic acid; octanoic acid; diethyl phthalate; benzene propionic acid; *1*,*3*-dihydroxybenzene; galaxolide; paracetamol; benzene acetic acid. Phthalates were not completely removed, and the concentration increased to reach 5.79 g/L inside the reactor at the end of the treatment process. This highlights the correlation between the irreversible toxicity observed due to the high organic load rates and phthalate accumulation inside the membrane bioreactor [43]; such correlation can be used to develop the best management practices to assure no toxic residues are left behind.

In Tunisia, phosphogypsum was previously mentioned to be a hazardous waste because its leachate is of high concern to underground water resources. The main environmental contamination was associated with the presence of fluoride, sulfate, calcium, phosphate, and trace elements or radionuclides movement into groundwater [36]. High conductivity, phosphates, low pH, and high concentrations of Cr, Cd, Zn, Cu, Fe, and Al were recorded by Melki and Gueddari [30].

3.4 Solid Waste Management

3.4.1 Institutional Framework

Waste management is a multi-stakeholders' shared responsibility between public national, regional, and local bodies and the private sector. At the national level, the following public institutions are involved:

- The Ministry of Interior (Formerly Ministry of Interior and Local Authorities);
- The Ministry of Local Authorities and the Environment (Formerly Ministry of Environment);
- The National Environmental Protection Agency, ANPE;
- The National Sanitation Utility, ONAS;
- The International Center for Environmental Technology, CITET;
- The Ministry of Public Health [40].

Solid waste management encompasses collection, transport to transfer centers, and disposal in landfills. All these operations are under the responsibility of the Ministry of Interior where a central department was created for this purpose. Regional and local departments were created in the 24 country's governorates and in the 264 municipalities, respectively [12].

On a local level, the municipalities are the structures in charge of waste management as stipulated by the Communities Organic Law and the law No. 96-41 related to control, management, and disposal of waste. Waste producers are also responsible for waste management as stipulated by the law No. 96-41 defining clearly the "polluter pays" and the "producer–retriever" principles [16]. The District of Tunis is a very specific case where the Municipal Agency for the Treatment and Reuse of Waste (AMTVD) is in charge of solid waste management. Both at the national and local levels, the Municipal Development Authority (CPSCL), the Municipal Training

Center, and the National Federation of the Cities of Tunisia (FNVT) are the public institutions in charge of solid waste management.

Generally, the ministries and their related national agencies are assigned several roles for setting strategies, programs, and actions. Table 3.1 depicts the ministries and related agencies and their respective roles in waste management with very likely overlapping tasks. During 2005, ANPE and ANGed were responsible for landfill management and the transport of wastes from transfer centers to landfills. ANGed affiliates were responsible for collection and recycling of packaging materials, used oil, and batteries.

In urban areas, several mechanisms were set to facilitate collection, transport, treatment, and disposal of municipal wastes; meanwhile, in rural areas, the local and rural councils are the ones in charge of the collection, transport, and disposal; in this latter case, wastes are not treated. In industrial areas, GMGs are the ones responsible for collection and transport of non-hazardous wastes from industries. These GMGs are operating as associations to organize activities around the industrial area in order to improve the quality of life and to rehabilitate the polluted sites. Few years ago, GIZ had supported and facilitated several activities in this regard [27].

Since January 2011 and following the transformation that occurred at the political level of the country, Tunisia witnessed a substantial degradation of the environment caused by the mismanagement of solid wastes which wreaked havoc on the urban and rural environments resulting in hot spots of garbage and uncontrolled dumpsites [41]. Various types of solid wastes were observed in cities, watercourses, green parks, etc., caused by strikes and contests of workers in dumping and transfer centers. The hazardous waste treatment center in Jradou, and Guellala dumping center in Jerba Island, and the one planned in the city of Mahdia were pending or completely closed because of recurrent strikes and opponent population [14] (Table 3.2). This post-revolutionary situation was worsened by several factors including social, financial, institutional, regulatory, environmental, etc., as follows:

- Dissolution of the municipal and regional councils in urban and in the rural areas leading to the complete abandonment of some actions that were supposed to be undertaken by these structures, like the development of waste management plans;
- Financial issues faced by the councils;
- Recurrent workers' strikes and degradation of the equipment;
- Closure of several dumpsites after claims expressed by the populations living in surrounding areas;
- Lack of communication plan and information channels for managing the critical transitional phase in the country;
- Low commitment and reluctance of the private sector to invest in waste management;
- Low enforcement of the law;
- Overlaps in roles within urban councils and the ANGed in waste chain management;
- Low workers' productivity;
- Lack of environmental awareness among citizens [27].

Table 3.1 Ministries and national agencies involved in waste management sector at the national level [27]

Institution	Role
Ministry of Local Authorities and Environment (since 2017)	– Elaborating and conducting national policies for environmental protection – Elaborating regulations related to environmental protection (waste management)
Ministry of Interior	– Before 2017, it was the highest authority in charge of urban areas and regional councils – Monitoring and elaborating on investment and exploitation budgets in the urban areas
National Agency for Waste Management, ANGed	– Participating in setting the national strategies and waste management programs – Implementing and investing in waste management – Exploiting the infrastructures and transfer installation and controlled landfills of non-hazardous wastes – Exploiting the infrastructures and installations dedicated to industrial and hazardous wastes – Providing technical assistance to urban areas and industries in waste management
National Agency for Environmental Protection	– Controlling and regulating enforcement in waste management
Ministry of Finance	– Participating in the elaboration and setting of financial instruments of waste management and related tax recovery
Ministry of Public Health	– Controlling and management of wastes produced in public and private sectors
Ministry of Industry	– Participating in the elaboration and implementation of programs related to industrial wastes
Ministry of Trade	– Participating in the elaboration and implementation of programs related to commercial wastes
Ministry of Agriculture, Water Resources and Fisheries	– Participating in the elaboration of the regulation for the protection of the natural environment against pollution caused by waste management

Table 3.2 Controlled landfills created, under creation or still pending operation [14]

Landfill	Capacity (tons/day)
Jebel Chekir	2000
Bizerte	300
Nabeul	500 (closed during 2013–2014 because of the opposing population)
Sousse	450
Monastir	400 (pending due to limited capacity)
Kairouan	150
Sfax	550
Gabes	160
Medenine	110
Djerba Island	Operation pending (because of the opposing population)
Kerkennah Island	Operation pending (because of the opposing population)
Tunis Elkabouti	1000 (operation pending because of the opposing population)
Zaghouan	60
Mahdia	168 (operation pending because of the opposing population)
Tozeur	69 (operation pending because of the opposing population)
Sidi Bouzid	96
Kasserine	164
Gafsa	237
Beja/Jendouba	299 (site-related problem)
Siliana/Kef	268 (site-related problem)

Municipalities in charge of the households' garbage collection, transport, and treatment were unable to deliver on the latter two aspects because of the low benefit they were getting from waste collection and the precarious financial situation. Cost recovery for the collection, transfer, treatment, and disposal of municipal waste in the Greater Tunis metropolitan area was estimated at only 15% of the total cost [41].

The centralized administration has put more pressure on the development of the municipalities in dealing with waste management. The institutional level was somehow overlooked due to the clear trend toward the application of top-down rather than the bottom-up approach. Indeed, municipalities are given very little autonomy [14].

According to the new constitution, waste management is meant to be a shared responsibility between several structures already in place at different levels: national, regional, and local levels to work together with urban committees and regional and local councils. In non-communal areas, waste management is supposed to be under the responsibility of the existing governmental structures and regional councils. The latter is meant to provide the necessary infrastructure and engines for waste collection and to cover the entire cost of this activity [14].

In rural areas, the governorates and the delegations together with the regional councils are currently monitoring and financing waste management through their representatives or the rural council where they exist. The latter plays a consultative role and contributes to ensuring property and hygiene activities. Based on the decentralization principle stipulated by the new constitution, 17 new rural areas were created in 2015. However, the whole process is forecasted to be fully achieved only by 2030. Moreover, ANGed's participation in the rural areas is very restricted, if not completely inexistent. Actually, it is noteworthy to indicate that in rural areas, waste management is assigned to the regional councils and to the *ad hoc* delegations which activity is based on timely availability and capabilities to remediate to critical situations like the uncontrolled landfills, the accumulation of garbage in the streets, the contamination of water resources and soils, etc.

In general, several mechanisms, very specific to the rural area, are set to bring together the various actors intervening in waste management to allow coordination actions. These mechanisms are contrasting with the urban area where agreements are established between the Ministry of Interior and the Ministry of Environment. Currently, departments of local communities in rural areas have merged with the Ministry of Environment; meanwhile, municipalities in urban areas are shifting progressively toward an autonomous financial status in line with the governmental decentralization policy. These same mechanisms do exist at the regional level as meetings of regional councils; the latter are gathering representatives of administrative divisions, ministries, and elected people [14].

In addition to the central role of the government in waste management, the private sector plays a pivotal role. In that, it participates in waste collection, transfer, disposal, and transformation. About 998 private companies have been identified as working in waste management [39]. Besides, at the national level, about 4.5% of the special domestic wastes are collected by the private sector. The latter fully ensures transfer and burring into landfills. It is also in charge of the collection of used lubricant oils, ordinary industrial wastes, medical care activity waste, and special industrial waste [37].

The participation of the private sector in waste management in rural areas takes into consideration the operation contract (agreement) established between the rural council and the private company for one year or more. The agreement is usually limited to the collection of regular solid wastes and their disposal in uncontrolled landfill. Financing is made through the household taxes and depends strongly on the quality of the provided services [14].

Participation of NGOs and local associations in waste collection and/or raising awareness about hygiene and maintaining healthy environment among the population is encouraged only in areas with strong leadership. Some associations were established and supported by international and bilateral cooperative projects funded by large donors (like the ENPI-CBC-MED program). What would be tricky and questionable is the sustainability of these projects after completion, especially that rural areas may lack, at this point, tools and human capacities in the short and long term [14].

Social cohesion and local leadership in rural areas are deemed to be crucial as well and to have a remarkable impact on public services including waste management. Influential associations can mobilize people around public space cleanness including collection and storage of domestic wastes in household using adequate packaging till transfer, ensuring cleanness of public areas, etc. [14].

Up to now, the integrated and sustainable strategy of solid waste (2006–2016) resulted in establishing the PRONGIDD in 2006 that came to replace the PRONADGES created in 1990s (Box 2).

Box 2
The implementation of PRONADGES includes several actions. The followings are few examples worth mentioning:
- Construction of five controlled landfills for domestic and similar wastes in the governorates of Tunis, Béja, Jendouba, Siliana, and Medjez el Bab;
- Establishment of three transfer centers for domestic and similar wastes in the governorates of Ben Arous, Jedaida, and Sousse;
- Installation of two waste sorting units in the governorates of Tunis and Sousse and selective waste sorting unit at the pilot residential area of Cité d'El Khadra in Tunis City;
- Closure and rehabilitation of the uncontrolled landfill of Henchir El Yahoudia expending over 30 ha and its transformation into a public park;
- Construction of a composting unit in Béja governorate in 1995, having a capacity of 1000 tons/year;
- Launching of pilot a project for collecting of used oils and lubricants, implemented jointly by the Charguia industrial area and the Tunisian company for lubricants—SOTULUB;
- Installing pilot project for treating oil filters in the Charguia industrial area with a capacity of 2 tons/day (about 50% of the filters sold on the market at that time);
- Installing 470 collection points distributed across the country dedicated to collect used packaging, as part of the Eco-Lef system activities [20].

This strategy has set two main objectives: (i) to improve environmental protection by implementing integrated and sustainable management of waste and (ii) to promote a better quality of life for dwellers. In order to fulfill these objectives, the strategy was based on two main pillars: (i) preventive actions: consisting in reducing wastes at the source before they reach the environment, and (ii) participative approach: applied to promote the involvement of all the actors at the different stages of waste management starting from the design and planning to the project implementation [14].

Economic incentives including National Environmental Fund assistance are promoting the participation of the private sector in financing solid waste management and valorization. However, private subcontractors are paid based on the amount of waste collected, transported, and treated. Therefore, the incentives are still limited to reduction and revalorization of solid waste [9]. The private sector participation in the valorization of solid for gas production is still limited despite the existing potential [11].

3.4.2 Policy and Strategies

Waste management is one of the government priorities for environmental protection and one of the main orientations of the sustainable development. Waste management has evolved throughout the years and went through several stages. In the 1990s, the country has developed a national environmental action plan and has carried out several programs for its implementation. At that time, the public expenditures dedicated to environmental and natural resource management was around 1% of the country's GDP. One of the most significant programs initiated in the 1990s, to be conducted for the long term is the Mediterranean Environmental Technical Assistance Program (METAP) funded by the World Bank and implemented in 8 countries, including Tunisia, aiming to address environmental protection issues [41].

In 1995, a framework law on waste management was promulgated. Later during the year 2000, the government developed the PRONGIDD funded by several donors like the European Investment Bank and the German and Italian aid agencies, and realized out by ANPE [41] which was assigned the responsibility to manage municipal waste including the hazardous ones. A Country Environmental Performance Analysis (CEPA) was initiated by the World Bank to integrate environmental aspects into the country's economic development strategies. Within this framework, CEPA supported the adoption of an integrated approach focused on the technical and financial viability of investments in the sector [41].

The number of projects was in the pipe within the National Development Plan 2002–2006 which provided funds for the creation of 9 landfills in 101 municipalities with a total capacity of waste disposal of 800,000 tons per year. Also, treatment plants for hazardous industrial waste were planned, with a capacity of 70,000 tons, together with a number of studies for the rehabilitation of dumpsites. In the middle of the year's 2000, it was estimated that about 40% of total municipal waste was disposed of in sanitary landfills. Nevertheless, two-thirds of the urban population had to cope with around 400 uncontrolled dumpsites distributed throughout the country because of their inadequate design resulting in several technical and economic problems [41].

Closing unregulated dumpsites were supported by the World Bank as part of a governmental initiative aiming at reducing greenhouse gas emission. It was the first in the MENA region to link investments in waste management sector with income derived from the reduction of carbon emissions [41]. The public expenditures increased from US$ 2.0 million in 1992–1996 to US$ 45 million for 2000–2006 [9]. In 2006, Tunisia established the Integrated and Sustainable Strategy for Waste Management for the period 2006–2016. The strategy was very optimistic; it has identified several gaps to fill and forecasted substantial changes in a span of 10 years.

Tunisia has established the national strategy for the valorization of biodegradable wastes supported by a number of international key partners and organizations of international and regional scope, like the World Bank, GEF program, the European Bank of Investment, the European Union, BMZ, GIZ, KfW, KOICA, and JICA. In this framework, at the national level, the Ministry of Agriculture together with the Tunisian Union for Agriculture and Fishery (UTAP) and some private farmers gathered for setting the priority projects and initiatives to achieve the strategy. At the regional level, the Ministry of Higher Education and some regional departments took part as well. This strategy was based on the six pillars as follows:

- PPP promotion through the involvement of private farms in various cities throughout the country;
- Implementation of governmental projects in large agricultural public farms like El Ghazala or El Alem;
- Valorization of biodegradable wastes consisting in energy production from raw or sorted wastes and biogas production in some landfills of Tunis City and metropolitan areas together with 9 additional landfills in operation in other cities (Nabeul, Bizerte, Sousse, Monastir, Sfax, Kairouan, Djerba, and Medenine);
- Private project development like the valorization of poultry wastes in Sfax and Nabeul; collaboration with research institutions to work on olive mills project; Tunis City wholesale market project, etc;
- Installation and rehabilitation of digestion units in rural areas [4].

After the revolution, the new constitution of 2014 has clearly mentioned and promulgated the right of dwellers to a safe environment and has stated that the country will encourage and guarantee decentralized decision-making. Accordingly, waste management and all environmental issues will be under the responsibility of the municipalities.

In 2016, the commissioned study on "Formulation of a transient national strategy and action plans for the treatment of solid wastes in 3 pilot rural areas" was initiated to (i) contribute to the reduction of environmental pollution; (ii) reduce health risks among rural populations; (iii) improve the situation for a sustainable economic development in rural areas; (iv) reduce solid waste production and preventing negative impacts of waste on the environment; and valorize waste through reuse, recycling, or any other process that could retrieve reusable material [14].

3.4.3 Regulatory and Legal Framework

Waste management is a strategic pillar of Tunisia's environmental policy. It was established in order to achieve a substantial upgrading of the general environmental framework and environment preservation. From regulatory standing point, Tunisia's waste management policy was translated by the promulgation of a certain number of laws and decrees. The legislative and regulatory frameworks of waste management are deemed to be well established with a comprehensive legislative framework for environmental protection; they clearly define wastes and describe their management modalities in terms of control and disposal in landfills, in addition to roles' distribution among the different institutions. The role of the Ministry of Environment and its related agencies is also well depicted in case of law infringement. However, waste management is much more developed in the municipal areas, the so-called communal area, while non-communal areas are somehow overlooked [14]. Chronologically, the most relevant laws and decrees worth mentioning in this regard are the following:

- Law 1975-33 of 14/05/1975: promulgating the Organic Law of Communities entrusting waste collection in communal areas to municipalities;
- Law 1996-1941 of 10/06/1996: amended by the Law 2001-14 of January 30, 2001, on waste control, management, and disposal. Waste management is mainly framed by this law targeting:
  - Prevention and reduction of waste production and hazard especially at the stage of products manufacturing and distribution;
  - Valorization of wastes through recycling and reuse, or any other type of action that allows retrieving material and using them as an energy source;
  - Reservation of controlled landfills for ultimate wastes dumping as the latest stage after exhausting all possibilities of valorization [14].

This law came to enforce the "polluter pays" principle, to assign the responsibility of disposal to the producer, to organize the control of the elimination process, and to ordinate the way the wastes should be treated. It also classifies wastes, based on their origin into domestic and industrial waste, and based on their characteristics as hazardous, non-hazardous, and inert; the same classification is adopted for the corresponding landfills. This law is supported by several regulatory texts like the decree 97-1102 of 2/6:1997 which specifies the modalities of recycling and management of used bags and packaging, and the decree 2000-2339 of 10/10: 2000 that identifies the list of hazardous wastes [14].

- Law 92-122 of 29/12/1992 on the Finance Act 1993 for the management, and in particular Articles 35-37 for the establishment of the Depollution Fund (FODEP);
- Decree 2317-2005 of 22/8/2005 related to the establishment of the National Waste Management Agency (ANGed);
- Decree 726-1989 of 10/6/1989 relating to rural councils establishment and entrusting waste disposal in rural areas to elected rural councils.

Some regulatory texts apply a preventive approach like the decree of 13/03/1991 related to environmental impact studies [20].

There are decrees that define conditions and modalities of management of some specific wastes like medical wastes, biosolids produced in treatment plants, slaughterhouses wastes, organic wastes, and many others, as well as the list of hazardous wastes. However, in the case of medical waste, some hospitals make no effort to sort and treat their hazardous wastes disposing them of like regular municipal wastes; thereby, they are dumped in uncontrolled landfills with negative repercussions on environmental and health. Mismanagement of biosolids was of great concern since 1989 when their use by farmers as organic fertilizer in agriculture was banned. They were disposed of in the watercourses and the receiving environment, thus causing health discomfort and environmental nuisance (Fig. 3.4).

Fig. 3.4 On-site disposal/storage of biosolids in the treatment plants. Courtesy of Olfa Mahjoub (2013)

3.4.4 Financing and Economic

Waste management financing mechanism is explicitly stated in the framework Law 96-41 of June 10, 1996 related to solid waste control, management, and elimination. The application of "*the polluter pays*" and "*the producer–recovers*" (producer responsibility schema) principle is one of the major principles promoted by this law, thus facilitating waste management financing" [22].

For cost recovery, two separate systems were put in place: (i) a system for collection and transport of solid wastes assured mainly by urban communities and by the state services in rural areas, and (ii) a system for the transport and disposal of the solid wastes (controlled landfills and transfer centers), financed by eco-taxes and local communities.

Tunisia has a national mechanism, called "The Loan and Support Fund for Local Communities" (Caisse des Prêts et de Soutien aux Collectivités Publiques Locales, CPSCL) for waste management financing. CPSCL was created in 1975 and revisited in 1992 to be transformed into a public industrial and commercial institution (EPIC). The CPSCL assures financing the municipal investments especially the acquisition of equipment. Since 1994, it has funded purchasing of several equipments for municipal waste collection and controlled landfills. CPSCL financed municipalities with low-interest loans for purchasing equipment and infrastructures and for waste management. Actually, municipalities are covering only about 5% of the investment costs. Most transfer and disposal facilities are financed through the state budget with some financial support from international and bilateral institutions [9].

There is no specific solid waste management cost recovery system in Tunisia. Municipalities use local taxes to finance direct operating costs of waste collection and disposal. These taxes recover part of this cost, and the shortfall is made up from other local municipal revenues [9].

Apart from ANGed, several other ministries and institutions are in charge of waste management financing. For instance, Ministry of Development, Investment, and International Cooperation, PNUD, the Tunisia Observatory for Environment and Development (OTED) may contribute to fund-raising. The latter has established a network dedicated to "wastes" to control, waste discharge in the environment as it is in charge of the elaboration of indicators on the environmental status [22].

For local communities, the cost of waste collection and transport is clearly mentioned in the local fiscal code promulgated by the law 97-11 of February 1997. The main mechanism in place is a tax to be paid by buildings, which corresponds to the cost recovery of cleaning services and housekeeping. This tax is calculated based on 2% of the reference rate per square meter multiplied by the surface area of the building.

In urban areas, collection and transport of wastes can be self-funded by the urban area funds. In rural, non-communed areas, financial transfer and state donation are covering a great part of the services cost related to collection and transport of solid waste organized by the regional committees and the rural councils. Collection and transportation services may be outsourced by a private operator through an agreement signed with the rural council.

Some national programs were established specifically at the regional level, called Regional Development Programs (PDR) and the Integrated Rural Development Programs (PDRI) are all incentives for the regional committees. The cost of solid waste collection and transport by the private operators is recovered from the dwellers; however, the recovery rate is limited to 30%. This rate was quite higher when fines were applied to offenders with the help of national police. Very few similar mechanisms do exist in rural areas [22].

Municipalities have very limited budget and may need financial support from other institutions [22]. ANGed is in charge of the implementation of the program of realization and exploitation of controlled landfills and transfer centers. Infrastructure financing is assured by eco-taxes and the support of technical and financial partners. Urban areas contribute to the cost of waste transfer to the landfill at a rate of only 20%. Actually, waste management consumes about 30% of the budget.

FODEP is a financial instrument that has been installed by law n°92-122 and established in 1993 to enhance actions dedicated to environmental protection against industrial pollution through the contribution in project financing, especially those related to collection units, recycling and valorization of wastes. FODEP is managed by ANPE, and project financing does adhere to authorizations set by the legislation and the approval of ANPE. FODEP's role in financing is stipulated by the decree No 93-2120 of 25 October 1993 modified and amended by the decree No 2005-2636 of September 24, 2005. FODEF also collects the eco-taxes and finances the participation of the state in the investment costs and exploitation of the controlled landfills and waste transfer centers. As of 2006, the FODEP has contributed in extending funds to 420 pollution mitigation projects, waste collection, treatment, and recycling projects and clean technologies projects [14].

In rural area, the situation is not better than that in urban area; funds and equipments allocated by the regional committees are deemed to be insufficient to assure an efficient collection and transport of solid waste. Besides, there is no cost recovery for waste collection and transport. In urban area, the average recovery of municipal taxes does not exceed 30% [14].

For all collection, recycling and waste sorting projects, FODEP can offer up to 20% of subsidies with self-funding of only of 30%; the remaining 50% of investment can be covered with a loan at a preferential rate to be paid over 10 years, with 3 years of exoneration. These projects are exonerated from customer taxes for any type of equipment specific for collection, sorting, recycling, or treatment of wastes. Besides, they are entirely exonerated from import tariff and tax payment (VAT) [27].

Local councils have limited financial resources to execute waste collection, while they do have no additional budget for waste transfer to the corresponding center and then discharge into landfills. Local taxes are the main funding source for waste management at the local level. Besides, households do not pay taxes for waste collection; therefore, municipalities may recover taxes from the private sector, which is very often claimed as unfair [14]

3.4.5 Communication and Sensitization

One of the weaknesses of waste management in Tunisia was identified as the lack of communication and exchange of information. In the framework of the integrated and sustainable national strategy for waste management, ANGed has decided to improve communication and sensitization around waste management for the period 2006–2016. It has established a program to develop an information system for wastes (SID) which was considered as one of the strategy's pillars. Data of various nature and types on waste management regularly published in the national and regional reports on the status of the environment were used as indicators [2].

Since 2016, ANGed has launched an initiative called "Thursday's Waste" consisting in organizing a monthly meeting to gather all actors working in the waste management sector, including public institutions, private sector, and civil society organizations involved in waste management and hygiene to discuss various topics like waste management, e-wastes, medical care waste, etc. [5].

A national program for sensitization of the population about composting at small scale was established in several governorates. Globally, 26 municipalities have signed agreements with associations for the installation of decentralized systems for each community of 30 households in pilot districts and 2 schools. About 22 municipalities were involved and material and equipment were distributed to households and schools; the remaining beneficiaries will join the programme for the period 2017-2020 and the program is expected to be extended across the whole country. Training sessions were organized for the municipalities and civil society organizations in addition to the distribution of around 300 composting boxes [5].

Besides, an initiative called "Houmti Tayara" (standing for my "neighborhood is great") supported by EU was jointly established in agreement with civil society to promote selective sorting and waste recycling at household level, and waste management. ANGed is also working on a program for enhancing the acceptability of the population to the installation of domestic waste dumping sites [5].

3.4.6 Technologies and Innovations

Before applying any type of treatment and regardless of the selected process used for domestic solid wastes, the following principles have to be considered:

- Waste composition;
- Potential ways to valorize the subproducts (compost, electric/thermal energy, paper, glass, etc.);
- Compliance of the domestic wastes with standards;
- Compliance with national environmental legislative and regulatory aspects;
- Cost of all the operations including collection, transport, treatment, and burring;
- Participation of dwellers in the collection and acceptance of products;
- Political will;
- Existence of a potential market for subproducts [23].

Based on waste composition, sorting operations either they are manual or mechanical, it is necessary before applying any kind of treatment process; all emissions, products, and wastes should comply with the national regulations, if not, with the European ones. For domestic waste, three main technologies were deemed appropriate: mechanical, thermal, and biological processes. Mechanical sorting can be applied for the valorization of material either recyclable or not and depending on material type. Thermal processes include incineration, thermolysis, wet oxidation, incineration of fuels after sorting the organic matter. The biological processes encompass composting, biostabilization, and methanization. Among all the studied treatment processes, several were completely discarded due to their low efficiency with regard to domestic waste like pyrolysis of raw wastes without sorting, hot plasma torch, transformation into fuels, sorting—extrusion, physicochemical process, etc. [23].

The most convenient processes fit for the types of wastes produced in the country include the following:

- Thermal valorization: This option is not applicable for now due to waste composition. In fact, this was recommended as a long-term solution that could be applied only to the incinerable fraction.
- Industrial/regular composting: These two options can be easily applied in urban and rural areas and for any quantity of wastes which may have economic benefits, in that landfills may be less expensive and less polluting with a longer shelf life.
- Industrial/regular biostabilization: This process was featured as appropriate to reduce waste quantity and dumping in landfill. This would contribute to improving compost quality with a subsequent market able to commercialize new products.
- Methanization is a process suitable for producing methane gas which then is used to generate electricity and reducing the quantity of wastes that would end up in dumping sites, thus resulting in less polluting and expensive landfills.
- Any combination of the above-cited treatment processes. These combined processes are flexible and depend largely on waste composition. Several combinations are based on sorting and incineration as a very first step. These two may be followed by either biostabilization or methanization. The final product is expected

to end up in the landfill or to be composted and then disposed of into dumpsites. The last option is based on gasification and methanization. All these combinations are useful in urban areas where wastes have variable composition. Their flexibility is less random and risky. Disposal of the final products in the landfill is the final step required by all these processes [23].

Based on waste composition and analysis, solid waste cannot be directly incinerated; they should undergo a special treatment beforehand. Incineration process is feasible and would be environmentally sound because it may reduce the quantity of waste up to 90%, significantly mitigate the risks related to leachates, reduce methane emission, and substitute oil used for energy production; 5 tons of organic matter can produce up to 1 ton of oil [14].

Composting process started in a pilot plant in a region called Lihoudiya that has been in operation during the period 1991–1998; indeed, the very first full-scale composting units were established in 1994. Private composting units like Cutivalor and La Verte Service were established later on [14]. Other examples can be cited like the one in Djerba Island (Box 3).

Box 3

Waste management in Djerba Island was particularly crucial. The city was facing several problems that resulted in serious environmental threats because of dwellers' behavior. The latter are used to dispose of their domestic wastes not into but near the dumpsters. This situation resulted in a very serious environmental pollution with an aesthetic view of community streets.

Based on the waste composition, moisture content, and the very high content in organic matter, disposing these wastes in landfill would release bad odor, on one hand, and cause leachate problems. The landfill in operating since 2007 has caused a lot of nuisance to local population. To tackle this issue, a project was launched to implement a platform for organic waste composting and to create selected waste disposal sites in some specific areas. The creation of organic/green waste compost was considered as a priority [12].

The valorization and recycling of organic wastes, like domestic and green wastes, biosolids, etc., by composting was one of the pillars of the National Strategy for Sustainable Waste management. Composting was recommended as very suitable for the national context. Despite the great potential existing in the country, very few actions were undertaken up to date [14]. The population is still showing high reluctance toward using compost derived from domestic wastes. Selective sorting of domestic waste at household level would be the very first step to take to overcome the psychological barrier. It was thought not to be applicable, and only 35% of the domestic waste, mainly the recyclable ones, may undergo this process [14].

Agricultural wastes are an important source of biomass for energy production. Following the oil crisis, some developed countries decided to develop energy-saving-based strategies and to develop research programs for the use of renewable energies for various purposes. Biomass is one of the renewable clean energy sources by far as it can be used in various sectors, like agriculture and industry. In the developed countries, up to 10% of the biomass is used while in Tunisia biomass may represent up to 60% of the energy sources in urban areas and up to 90% in rural areas.

Apart from technologies, innovative actions were undertaken. Mobile applications were made available to citizens in the town of Grombalia, Djerba, and Kasserine to assist in enforcing the law by giving the citizens a platform to help authorities monitoring any illegal dumping, to enhance citizens' participation, and to facilitate waste collection services. The application of geodatabase using GIS, GPS tracking, and satellite images, and utilizing data reported in the literature were suggested as solutions to facilitate collection and transport of solid waste [11].

3.5 Conclusions

The major milestones of the waste management sector in Tunisia were comprehensively presented in this chapter with an insight into the main achievements. This work has unveiled that it took more than two decades to Tunisia to establish its regulatory and institutional frameworks for solid waste management. Quick progress has been witnessed during the early 1990s characterized by the establishment of several laws and legislations. Nowadays, this framework has to be revisited and enforced. Institutions were created, and their respective roles were clearly defined followed by strategies, national programs, and actions for their implementation at national, regional, and local levels. Significant goals were met while targeting sustainable and integrated waste management during the last decade. Waste management is relatively well organized in the municipal areas despite the existing weaknesses; meanwhile, rural areas are still lagging behind, facing huge environmental problems caused by the release of liquid and solid waste. Since 2011, the situation in both areas has regressed, calling for strong governance and involvement of the private sector with solid support of the civil society; this is the prerequisite to succeed the decentralization process. Decentralization of decision-making represents the main challenge of the upcoming years despite some uncertainty. It is also an opportunity to enhance ownership, to empower local government, and to strengthen the role of communities. In this new venture, a strong political will is required targeting the societal benefit. Citizens should play a key role by thinking global and acting local to identify sustainable and economically viable alternatives to liquid and solid waste disposal that could be scaled up.

3.6 Recommendations

In light of the state of the art of liquid and solid waste management in Tunisia and of the lessons learnt during more than two decades, the followings are recommended:

- Conveying the clear message that waste management does start in the upstream and potential pollution risks incurred by the environment and the population is society's responsibility; the government's role is assigning roles, prioritization of actions, allocation of funds, and regulations setting to guarantee a harmonized framework.
- Meeting the SDGs connected to liquid and solid waste management for the year 2030 requires identifying the right indicators and realistic objectives built on reliable figures and data.
- Regulations' enforcement and revision of laws in a way that fits with the future societal challenge, the vision of the government. The "polluter pays" principle should be rigourously implemented regardless of the entity either it is an institution or a person.
- Empowering civil society, voluntary actions, citizens' initiatives, and investing in youth capacities to innovate.
- Providing outreach to the increasing low-income populations living in remote areas.
- Encouraging small and local actions rather than costly and large programmes requiring more efforts and capacities to reach their goals.
- Better management of projects financed by international organizations by ensuring follow-up.
- Exploration of all actions and ways to make waste an asset not a burden to the society, the environment, and the country.

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Chapter 4
Detection and Prediction of Geo-environmental Hazards in Urban Areas and Desert Lands Using an Integrated Structural and Geophysical Approach: Cases from Egypt

Mohamed Attwa, Ahmed Henaish and Sara Zamzam

Abstract Nowadays, geo-environmental assessment becomes an immediate concern all over the world. In general, the flow paths of pollutants and radioactive source allocations are related to rock types, subsurface layer distributions and structural settings. Thus, this chapter aims to present a non-conventional integrative approach of remote sensing, structural data and geophysical methods for geo-environmental hazard assessment. Notably, such hazards commonly result from human activities where contaminants are accumulated and spread on or beneath the ground surface. Detection of organic contamination and hydrocarbon flow path is a difficult task for geophysical techniques at hazardous waste areas. Furthermore, radioactive-emission detection is of specific value in the vicinity of mineral resources for human health and environmental preservation. Accordingly, waste management as well as a subsurface contaminant and geological structure mapping are prerequisite for urbanization, mining and civil engineering. In this chapter, we presented cases for waste management to indicate how recent technologies can be used for detection and prediction of geo-environmental hazards in urban areas and desert lands. The following techniques are used to achieve the objective of the chapter: (1) remote sensing, (2) information on structural geology, (3) direct current (DC) resistivity method and (4) airborne geophysics. Regarding four case studies, the results indicate the effectiveness of the suggested approach to map surface and subsurface geological conditions concerning the pollutants and radioactive emissions in 2D/3D. Even when the contaminant itself produces no detectable direct geophysical signature, sometimes it may be found by indirect means through the structural mapping as a guide to predict the contaminant flow paths. Accordingly, the approach will be helpful to the decision-makers to achieve sustainable development in urban and desert areas regarding the waste

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management aspects. Moreover, the present nondestructive approach can be considered as an initial step in waste assessment projects.

Keywords Waste management · Geo-environmental assessment · DC resistivity tomography · Magnetic and radiometric methods · Remote sensing · Structural geophysics

4.1 Introduction

In many places of the world, sustainable development and geo-environmental assessment have become more extensively prompted. Consequently, environmental scientist and engineers should work together to introduce non-conventional approaches that can protect our environment from the detrimental aftereffects of urbanization and industrializations. Too often, many environmental and engineering problems are observed after urbanization, especially in many developing countries. Because mining, industrial sites, waste disposal areas and landfill sites are necessary parts as infrastructures in new urban areas, geological and geotechnical assessment has to be carried out for site investigation to avoid geo-engineering and environmental hazards. Therefore, it is important to develop the interdisciplinary solutions to allow the socioeconomic groups and nations to gain sustainable clean environment. As an example, understanding the fault rupture hazard impact on the constructions and new communities is essential for informing policy and future science directions.

Characterizing and understanding subsurface structures, engineering hazards and contaminations for sustainable development are time-consuming and impose particular challenges applying traditional drilling processes. Recently, specialists in geological structures, remote sensing (RS) and geophysics formulate approaches related to their sister discipline for environmental and engineering issues [e.g., 1, 2]. Recently, RS has been widely used for providing regional geoscientific data in a relatively short time. Site characterization and preliminary environmental and engineering assessment can be carried out using aerial photographs, Landsat images. RS techniques can show the changes in the spatial resolution and different times for sites subjected to geomorphological and environmental hazards [e.g., 3, 4]. Moreover, structural mapping for defining an accurate fold/fault location, strike and dip can be easily presented using high-resolution Landsat images in a short time [5].

Geophysical techniques are currently used to develop the geology model of new development areas to characterize the fracture zones, investigate groundwater [e.g., 6–9] and delineate the landfill/contaminated zones [10, 11]. Furthermore, the mining at new desert areas is carried out using multitude techniques of RS and geophysical methods [e.g., 12, 13]. Recently, geophysical and geological studies are recently used to investigate subsurface structures and lateral heterogeneities to delineate the fractures concerning geo-engineering hazards [e.g., 14, 15]. In general, all geophysical methods (e.g., magnetic, gravity, electrical and seismic) depend on the existence of contrast in the values of physical parameters (e.g., magnetic susceptibility, density, resistivity and velocity) of rocks and soils. Such parameters have to be considered at the site before geophysical surveys.

4.2 Waste Hazards and Chapter Objectives

Wastes have potential effect on environment and public health. They can be found in different physical states such as gaseous, liquids or solids. Waste disposals are hazardous and can be found in many fields which have a direct relationship to geological system, e.g., petroleum industries, mining and urban communities. Detection and prediction of hazardous waste localities or path flows are immediate concerns in the field of waste management to reduce the hazards affecting human and environment. Several methods can be used for detection and prediction of hazardous wastes that affect many localities. Geological mapping and geophysical imaging are such important tools that can be used in detecting hazardous wastes. Herein, in this chapter, an approach is suggested for waste management which is provided by many geo-environmental problems.

Here, we will focus on the efficiency of an integrative approach using geophysics and structural data for detection and prediction of geo-environmental hazards in urban areas and desert lands. The principles of structural geology, RS, magnetic, radiometric and direct current (DC) resistivity techniques will be summarized (i.e., general background) showing the efficiency of these methods for sustainable development. Finally, case studies will be presented to assess, investigate and understand the present integrative approach for wastewater management, geo-engineering hazard prediction, environmental hazards caused by the radioactive-emission imaging and hydrocarbon leakage detection.

4.3 Structural Geology

Structural geology is a significant part of engineering geology, which deals with the physical and mechanical properties of rocks. Geological structures are an internal weakness of rocks which may influence the stability of human engineered constructions such as dams, roads, pit mines and underground mines or road tunnels. Structural geology is very important to environmental geologists as well as hydrogeologists to understand how geologic sites are impacted by groundwater flow and penetration. Accordingly, detailed structural mapping and analysis can have significant engineering and environmental impacts, including highly faulted/fracture zone mapping.

The last decades experienced a rapid enlargement in urbanization all over the world. Therefore, understanding the subsurface structures in highly deformed localities is necessary for sustainable development. Consequently, without proper geological and engineering investigations of such regions, undesirable geo-engineering problems may arise in striking ways, e.g., dramatic tilting. Structural geologists apply many techniques in order to: (i) characterize deformation structures (geometry), (ii) reconstruct their deformational histories (kinematics) and (iii) estimate the stress field including the direction and magnitude of the forces that resulted in that deformation (dynamics). Once a structural geologist examines geological structures in the field, the main goal is to establish their mechanism of formation. The reason the structural geologist challenges to categorize geological structures by their mechanism of formation is that this aids the allocation of each structure to a definite stress field or geological setting. Moreover, structural geologists study the crosscutting relations of different structures to find out their relative age. This information can be significant in determining the structural history of an area and to investigate the changes in the regional and local stress fields through time.

There are different types of stress affecting rocks, and these determine how the rocks deform. Tensional stress means that the rock is stretched apart, while compressional stress occurs when the rock is pressed together. Shear stress is when rock slips in a horizontal direction. A deformational feature observed on one scale typically reflects processes occurring on other scales. As rocks are stressed, they go through phases of deformation. Rocks may be deformed that the change is not reversible, which is called ductile deformation. Ductile means that rocks can be altered into a new shape and stays that way. Where the rocks are highly stressed, they fracture, and the change is irreversible, which is called brittle deformation. Deformation (or strain) results from stresses that exceed rock strength. When strength is exceeded, the rock will fail by brittle (by fracturing or faulting) or ductile (by folding) deformation, depending on how the physical environment has affected the ability of the rock to resist the stresses (Fig. 4.1). Fractures are planar or sub-planar discontinuities that are very narrow in one dimension in contrast to the other two and form as a result of external or internal stress. Fractures can be classified into shear fractures, opening or extension fractures (joints, fissures and veins) and closing or contraction fractures (stylolites) (Fig. 4.1). Faults are discrete fractures that take place on all scales in the lithosphere between blocks of rock which have been dislocated relative to each other, in a direction parallel to the plane of fracture. Shear sense on a dip-slip fault is described with reference to a horizontal line on the fault, by saying that the movement is hanging-wall up or hanging-wall down relative to the footwall by translation up or down the dip of the fault plane. Faults are called normal faults where hanging-wall down, while they are called reverse faults where hanging-wall up. Strike-slip faults accommodate horizontal slip between nearby blocks. They are described as left-handed (sinistral) or right-handed (dextral), depending on the sense of actual relative movement (see Fig. 4.1).

Folds are wave-like structures that are produced by ductile deformation varying in size (i.e., microscopic crinkles to mountain size). Convex upward and downward folds can be defined as an antiform and a synform, respectively. The inner region, a folded layer concave side, is the fold core. Syncline (synforms) and anticline (antiforms) are stratigraphic significance terms. In anticlines, the oldest strata are found in the fold core. In synclines, the youngest strata are found in the foldcore.

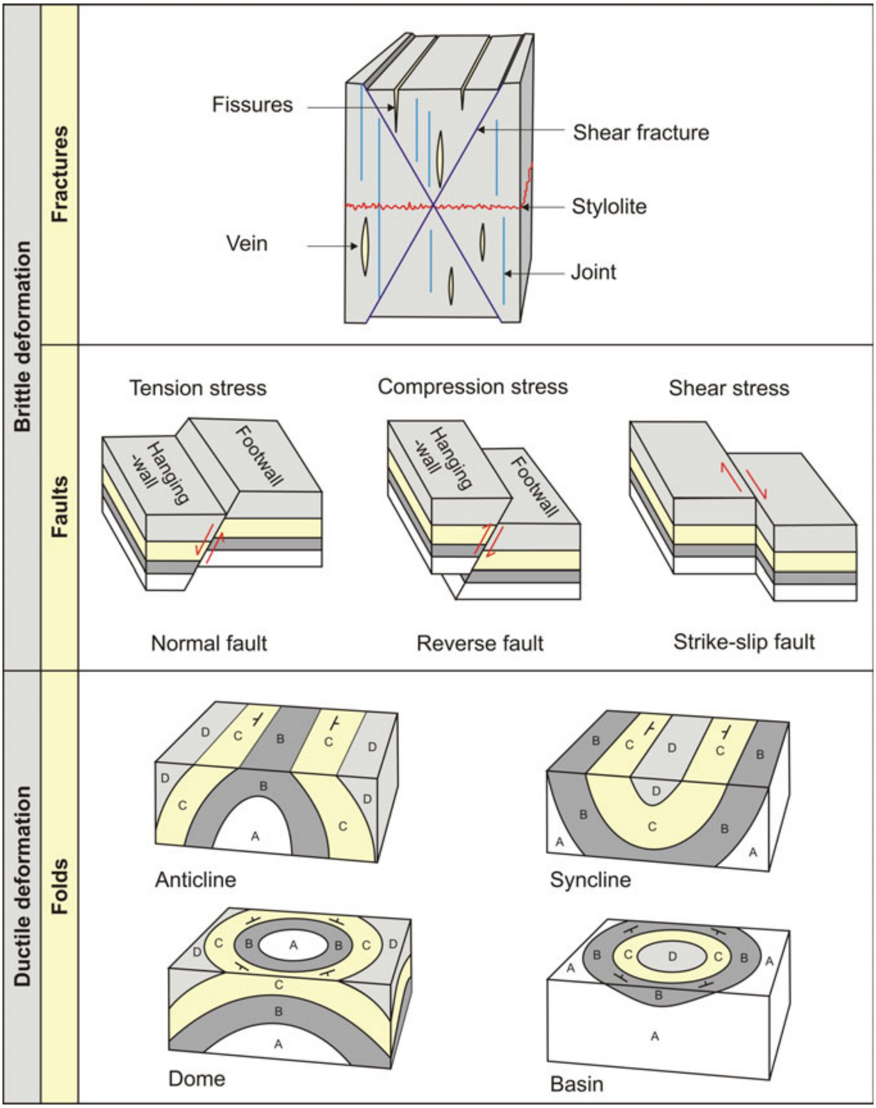

Fig. 4.1 Main geological structures (fractures, faults, folds) resulted from brittle and ductile deformation

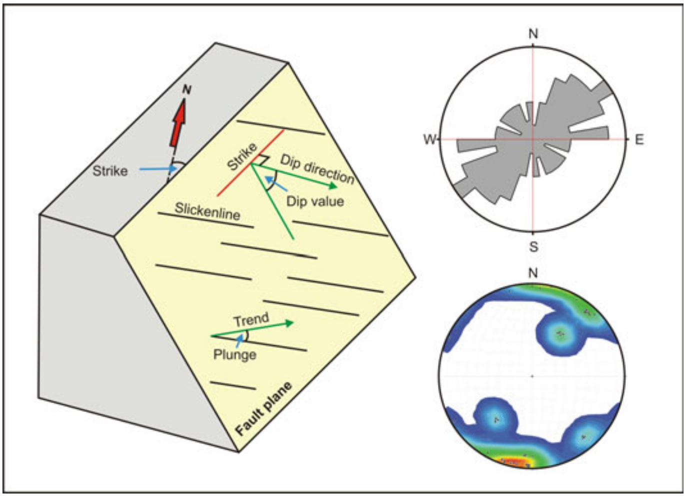

Fig. 4.2 Measurement principles for planar and linear structures which can be further analyzed using rose diagrams or stereographic projection

A circular or oval shaped antiform is termed a dome. In contrast, a synform shows that bedding planes dip inward toward a central point in a basin (see Fig. 4.1).

In the field, structural geologists collect principal data sets which are measured from planar features (e.g., bedding planes, faults, fractures, fold axial plane) as well as linear features (e.g., fold axis, slickenlines). Structural data are collected using a professional compass (e.g., Brunton compass). The planar features are recorded in the form of strike and dip, whereas linear features are recorded in the form of trend and plunge (Fig. 4.2). Further, the collected data from the field are analyzed using different methods (e.g., stereographic projection, rose diagram) for assessing the nature and orientation of geological structures (Fig. 4.1). Rock geometry measurements are used to understand the deformational history of rocks. Once geologists understand the relationships between stress and strain in rocks, they can interpret the observed patterns of rock deformation into a stress field during the geologic history.

4.4 Remote Sensing (RS)

RS is the science of gaining information about different materials on the earth's surface without actually having direct contact with it. This is done by recognizing and recording reflected or released spectral data from the earth's surface and then processing and resolving that information. The basic role of RS is utilizing reflectance spectroscopy to distinguish the change in chemical and/or mineralogical composition across a large area by gathering spectroscopic information along discrete wavelength regions (bands). The bands cover fractions of the electromagnetic waves (EMWs)

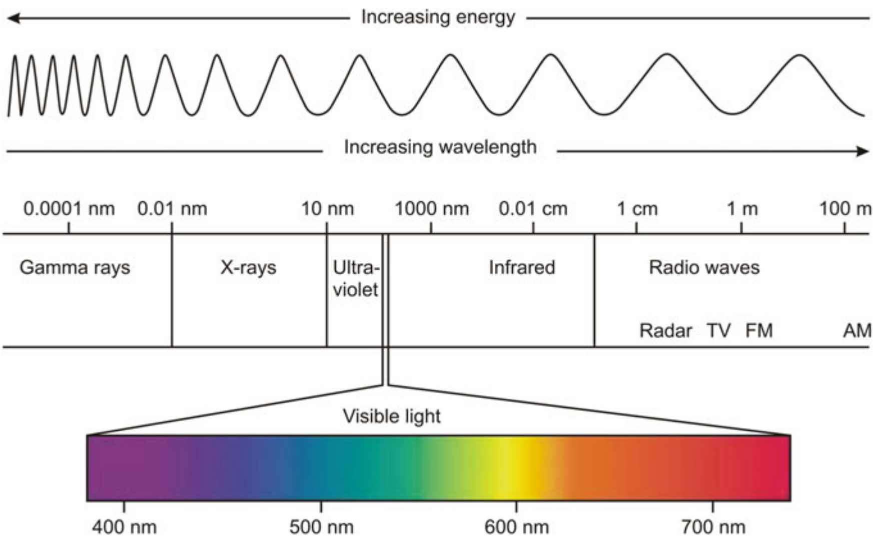

Fig. 4.3 Electromagnetic waves used in remote sensing

called atmospheric windows (Fig. 4.3). There are two main groups for EMW sensors: passive and active. Passive sensors record existing levels of natural sources of energy, while active ones have their own artificial source of energy. Each material has its own signature and depends on the pattern of its spectral response.

The main function of the scanning sensor is the mechanism of picking up a small field of vision (instantaneous field of view—IFOV) in the direction perpendicular to the direction of the satellite's movement (north–south). Regarding this movement, a complete raster image of the environment is created. Currently, images are collected and distributed to users by several satellite systems. The diversity in RS data (satellite images) is based on the used sensors (multispectral or hyperspectral), which extends from little spectral bands to more than 100 adjacent bands, covering the visible to the shortwave infrared regions of the electromagnetic spectrum.

The most familiar multispectral satellite images used in environmental and mapping applications are Landsat Thematic Mapper (TM), Advanced Spaceborne Thermal Emission and Reflection (ASTER) Radiometer and Radio Detection and Ranging (RADAR). Moreover, new and more precision hyperspectral data such as Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Moderate Resolution Imaging Spectroradiometer (MODIS) are used but in a limited domain. Each type of satellite data offers specific characteristics that make it more or less appropriate for a particular application. The spatial and spectral resolutions are the two essential characteristics that give a good help in preference to satellite data for any application. The spatial resolution means the size of the area on the land that is figured out by one data value in the imagery, while spectral resolution relates to the number and wavelength of the spectral windows that are captured by the satellite sensor from electromagnetic energy. Spectral signature measurement of different field rock types is a supplementary step, but it is important to get precision mapping.

The processing of digital image is involved mainly with three main operations: image preprocessing, classification and transformation. Image preprocessing is predominantly concerned with the correction, calibration and modification of images in order to achieve the most realistic representation of the earth surface with its appearance in a good visual system. This operation is a fundamental step for all applications. Visual analysis is important, even in digital image processing, and the effects of these techniques can be remarkable, for example, normalization and data stretching. In the image classification step, information classes are extracted from a multiband raster image such as supervised and unsupervised classifications. Moreover, different accuracy assessment techniques are used to make the analysis more powerful. This operation is vital to geographic information system (GIS). Finally, the image transformation step is assisted by the computer where the images are interpreted in addition to deriving new ones resulting from some mathematical treatment, for example, principal component analysis. With the advent of RS technology, its data have been used by geologists for regional mapping, structural interpretation, environmental assessment and prospecting for ores and hydrocarbons.

4.5 Airborne Geophysics (Magnetic and Radiometric Methods)

Airborne geophysical data provide the basis for a wide variety of geological and geophysical interpretation and modeling applications at both regional and local scales. The most critical issues in the geological enigma are the lithology, structural elements and the relation between both of them. Geological mapping with airborne geophysical data is widely employed due to cost-effectiveness and capability of providing information of areas that are not easily accessible. Such airborne surveys are usually done along parallel flight lines, which may be spaced from 100 m to a few kilometers apart (Fig. 4.4). The spaces used depend on the quality of detail needed, the flight elevation used and the intensity of exposure. The trend of the flight lines is chosen to be more or less normal to the orientation of interested or known subsurface features. Further tie-lines are flown at right angles to the main outline (Fig. 4.4). Their in-between distance is about 5–6 times that of the essential flight lines. The accuracy of the survey is verified by the repeatability of the readings at the intersections of the tie-lines with the main flight lines. Airborne geophysical magnetic and radiometric surveys have been used extensively for environmental radiation monitoring, mineral exploration, structure mapping and rock characterization.

The airborne sensing of environmental radioactivity is based mainly on the detection of gamma radiation. Gamma rays are the most penetrating emission from natural and human-made sources. The most significant internal source is the radioactive element potassium (K^{40}), uranium (U^{238}) and thorium (Th^{232}) decay series. Potassium

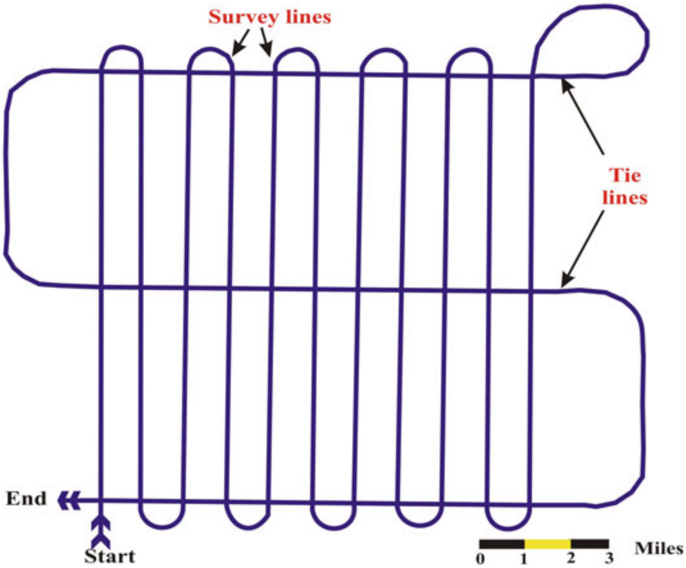

Fig. 4.4 Representation of the flight plan and tie acquisition lines of airborne geophysical survey

(K^{40}) is a major constituent of most rocks, while uranium and thorium are present in trace amounts, as mobile and immobile elements, respectively. Measured radiation distribution can be reliable to map and class different lithologies as a result of its different concentrations between different types of rocks (Fig. 4.5). The three main correction methods applied to increase the gamma radiation quality are radon, cosmic and instrumental background corrections. The most familiar method used for removing natural radon background is the use of upward-looking detectors that are capable of differentiating between aerial and earthy sources of radon radiation. Furthermore, the high-energy gamma rays that are produced from cosmic charged particles are estimated by its window count rate. Further, the instrument background refers to trace amounts of K, U and Th in the detector and surrounding equipment.

The airborne magnetic method played a prominent role in earth science by revealing subsurface information. Airborne magnetic maps generally show the variation in the magnetic field and hence reflect the distribution of magnetic minerals in the earth's crust. Irregularities in the magnetic field of the earth are caused by remnant or induced magnetism. The secondary magnetization induced in a ferrous body by the earth's field is the primary cause of the induced magnetic anomalies. Generally, igneous or metamorphic rocks have a very high magnetic susceptibility in contrast to sedimentary rocks, because they have a much higher magnetite content.

In order to make accurate magnetic anomaly data, some essential corrections must be applied such as diurnal, height, parallax/lag and removal of International Geomagnetic Reference Field (IGRF). Declination and inclination are the main factors that controlled the last mentioned correction. Different advanced processing meth-

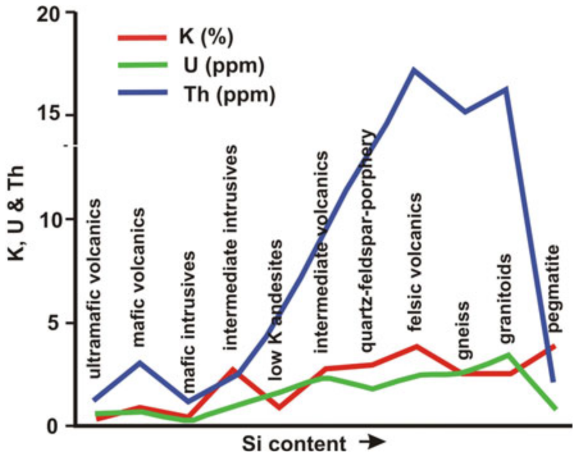

Fig. 4.5 Variation in average K, Th and U content in igneous rocks with increasing Si content [16]

ods provide tools for understanding both the regional distribution and the trends in geophysical properties to be related to near-surface and subsurface geology. The selection between different enhancement and transformation techniques depends on the geological question of interest. The first stage of the geophysical interpretation process can be described by two main steps: a preliminary picture of the existing geological data and analysis of regional geophysical data. Subsequently, as a final stage of the interpretation, the subsurface geology is estimated using advanced processing techniques and data integration in the 3D visualization.

4.6 Near-Surface Geophysics (DC Resistivity Method)

The direct current resistivity (DCR) technique was among the first geophysical methods developed. The DCR method uses an external power source using two current electrodes at the ground surface. The electric current propagates in the subsurface in three-dimensional. The subsurface physical information is given by measuring a voltage using another two electrodes (called potential). Such current and potential electrodes make up a four-electrode array (Fig. 4.6). Beneath the four-electrode form, the resistivity of subsurface volume can be calculated using Ohm's law. Accordingly, the electrical potential difference (ΔV) between M and N can be calculated as follows:

$$\Delta V = \frac{\rho I}{2\pi}\left(\frac{1}{\overline{AM}} - \frac{1}{\overline{BM}} - \frac{1}{\overline{AN}} + \frac{1}{\overline{BN}}\right) \quad (4.1)$$

where ρ is the overall soil resistivity, I is the electric current applied at the surface and ΔV is the potential difference between M and N electrodes.

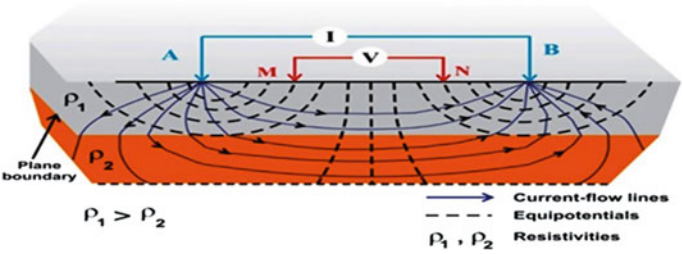

Fig. 4.6 A four-electrode array showing the electrical current flow in three-dimensional form

Equation (4.1) can be rearranged as follows with respect to ρ:

$$\rho = 2\pi \frac{\Delta V}{IG} \tag{4.2}$$

where G is a geometric factor related to the distances between current and potential electrodes.

For homogeneous and isotropic soil and rock, the calculated resistivity (ρ) from Eq. (4.2) can be considered as true resistivity. However, because the subsurface soil and rock are commonly heterogeneous, the measured resistivity is typically referred to as apparent resistivity (ρ_a).

In general, the basic resistivity survey uses conventional electrode configurations that have different current and potential electrode arrangements. The conventional three-electrode arrays are represented in Fig. 4.7. Considering the position of current and potential electrodes, the geometric factor is changed from one array to another (Fig. 4.7). The apparent resistivity for the common electrode arrays, Schlumberger (Eq. 4.3), Wenner (Eq. 4.4) and dipole–dipole (Eq. 4.5), can be calculated, respectively, as follows:

$$\rho_a = \frac{\Delta V}{I} \pi(n)(n+1)a \tag{4.3}$$

$$\rho_a = \frac{\Delta V}{I} 2\pi a \tag{4.4}$$

$$\rho_a = \frac{\Delta V}{I} \pi(n)(n+1)(n+2)a \tag{4.5}$$

The depth of investigation (DOI) of electrode arrays is, in general, in the range of $a/6$ to $a/4$, where "a" is the spacing between the outer active electrodes. Furthermore, each array has advantages and disadvantages including DOI, resolution and horizontal coverage. Accordingly, the location and the size of the surveyed area should be well studied.

The DCR measurements can be carried out using soundings and profiling/mapping survey. DCR soundings are commonly used for deep depth and horizontally layer

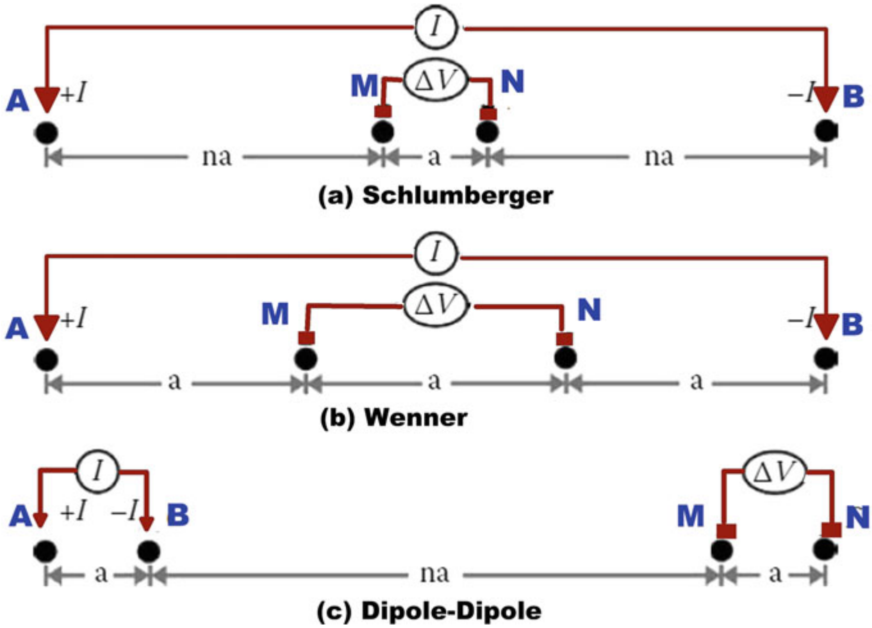

Fig. 4.7 Three common electrode configurations showing the arrangement of current and potential electrode spacing

ground investigations. Schlumberger array is commonly used for sounding survey. The interpretation of DCR soundings along a profile can be stitched to construct a geo-electrical cross section. On the other hand, profiling/mapping survey is commonly used for near-surface environmental and structural problems. The advantage of such a survey is its high horizontal and vertical resolution along a profile. The measured data along the 2D profile are plotted as a function position along the profile and electrode spacing in the form of "pseudosection." For conventional interpretation method, all inversion software needs a reasonable initial model. Such a starting model can be determined either by the user (e.g., borehole data) or the program itself. The final inverted model is calculated step by step in the iteration process. The calculated model (i.e., forward problem) is compared with field data until the best fit and/or selected deviation (error) is reached (i.e., inverse problem) (Fig. 4.8). In the case of non-conventional inversion technique (i.e., genetic algorithm), the data are not utilized in creation and model update. The way of parameter update depends on the global minimization type. In the biological simulation process, the genetic algorithm generates model updates and can validate a huge complicated and distinct model number. The details of principles and interpretation methods of the DCR technique were given in [17].

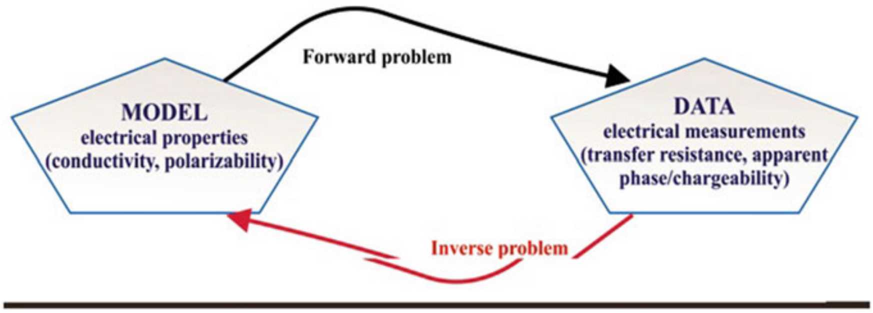

Fig. 4.8 Interpretation process of DCR data in the form of forward and inverse problems

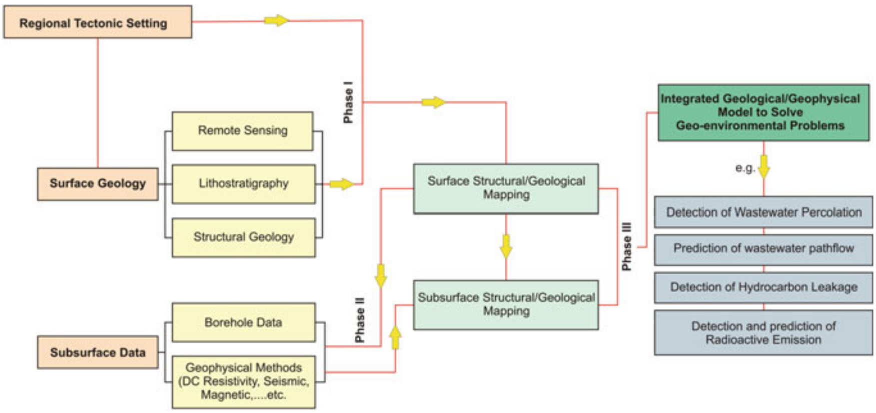

Fig. 4.9 Workflow for structural geophysics integration strategy

4.7 Structural Geophysics Integration Strategy

The structural geophysics integration strategy aims to combine structural geology and geophysical techniques in order to solve geological, engineering and environmental problems. The suggested strategy depends on using the surface geological data as a key while interpreting geophysical data which assess many geological controls that enhance subsurface modeling and reduce the geological uncertainty. The structural geophysics integration strategy workflow is summarized in Fig. 4.9.

In order to assess a reliable structural model, three phases must be followed up. Phase I is dealing with surface geology which includes a detailed surface study of the lithostratigraphic setting and mapping of surface exposed geological structures using RS techniques and fieldwork in order to record the geometrical parameters of such structures (e.g., strike, dip value, dip direction). Also, the regional tectonic framework and regional stress field must be considered. Following Phase I, surface geophysical surveys (Phase II) are conducted in order to image the subsurface structures and subsurface heterogeneities. In comparison with available boreholes and measured structural parameters (stage Phase I), corresponding subsurface information can get to reduce the uncertainty of the measured geophysical data. All detailed measured data of Phase I (e.g., strike and dip values of bedding planes and geometry of geological structures) are taken into consideration for controlling the geophysical data interpretation, Phase II. Finally, the derived surface and subsurface geological data (Phases I and II) are integrated into a reliable geometrical structural/stratigraphic model (Phase III).

4.8 Case Studies

A Wastewater percolation mapping

The Tenth of Ramadan city is a new urban area on the desert fringes of the eastern part of Nile Delta, Egypt. Based on field observation, all wastewater types including industrial and domestic sewage have been discharged into stabilization ponds (lagoons) (Fig. 4.10). Notably, the efficiency of such ponds is deteriorating due to the purification, lack of maintenance and the hydraulic overloads since they have been constructed.

Regarding the above-mentioned flowchart (Fig. 4.9), surface data using geological and borehole information were studied. In addition, the subsurface data were acquired using a geophysical method (i.e., DCR technique) in order to image the wastewater percolation from the adjacent oxidation ponds in Tenth of Ramadan city. All surface and subsurface data were integrated to detect the wastewater percolation in such case study. Accordingly, the DCR method was applied to understand the physical properties of the clay-rich cap and permeable zone to study the oxidation pond impact. Moreover, the discontinuities and detailed distribution of sand-rich zones were imaged to delineate the wastewater pathways around the ponds. Geophysically, DCR surveys were carried out in the form of 1D and 2D to assess the near-surface conditions around the oxidation ponds. The 2D imaging was processed and inverted using Boundless Electrical Resistivity Tomography (BERT) resistivity inversion program [18]. The BERT code depends on numerical modeling using finite-element technique.

Figure 4.11 shows the inversion results of three 2D DCR profiles measured around the oxidation ponds at Tenth of Ramadan city [11]. Two 2D profiles (P4 and P5) were represented in the form of 3D visualized model. The lateral heterogeneity within the near-surface soil around such oxidation ponds can be observed (Fig. 4.11, top). Notably, the wastewater percolation from such open drain and oxidation ponds increased along P5 in comparison with P4. On the other hand, the wastewater percolation decreased at the central area of the 2D profile P4. The high resistivity values along the central part of 2D profile P4 are attributed to the low degree around the oxidation pond. Along the 2D profile P5, the low resistivity values around the open

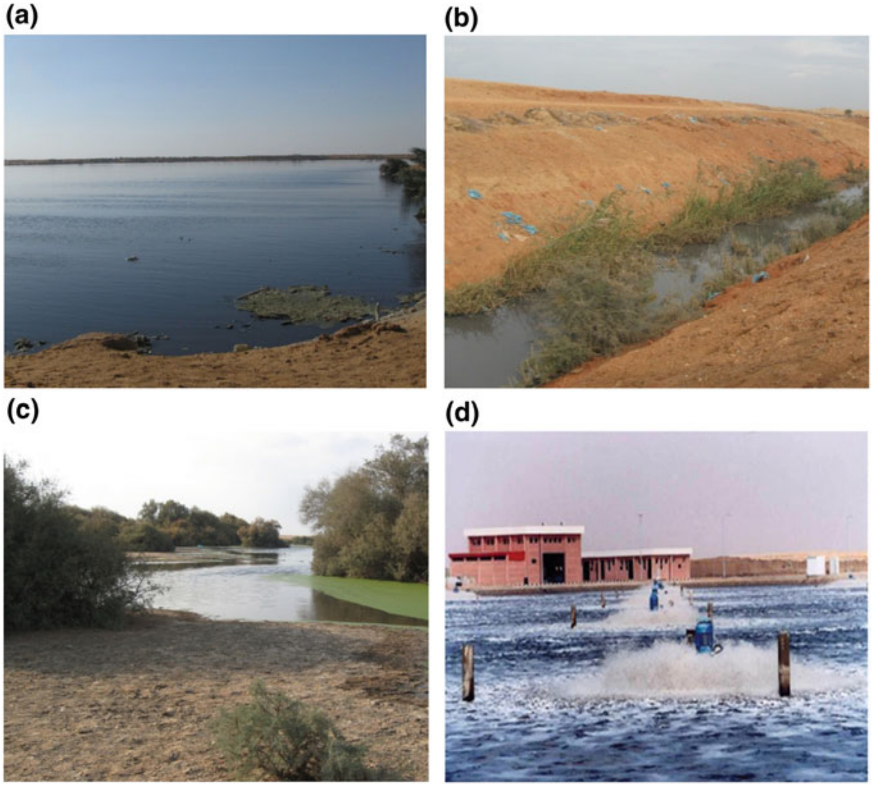

Fig. 4.10 Wastewater disposal images showing **a** oxidation pond, **b** pen surface drain, **c** wastewater seepage and **d** sanitation plant in the Tenth of Ramadan city

drain can be attributed to a high saturation zone with wastewater, which extends vertically to ~15 m.

Figure 4.11, bottom, shows the inversion results of 2D profile P6. Notably, the resistivity wide range can be related to the grain size distribution variation and water saturation degree. On the other hand, the high resistivity values occupied the entire profile line can be attributed to dry sand layer. The 2D profile P6 represents the presence of wedge-like shape close to the oxidation pond of medium resistivity layer. This can be attributed to the percolation the micro-fissured cemented walls of oxidation ponds. This profile (P6) indicates the efficiency of the DCR method to assess the environmental impact of wastewater percolation around the oxidation ponds in a new urban area.

B Structural imaging in predicting wastewater path flow

In Egypt, Cairo-Suez District (CSD) experiences a rapid increase in urbanization. The CSD has a complex structural setting in the form of faults and fracture zones within Eocene limestone rocks and shale. In such weak zones, paths for contaminant (e.g.,

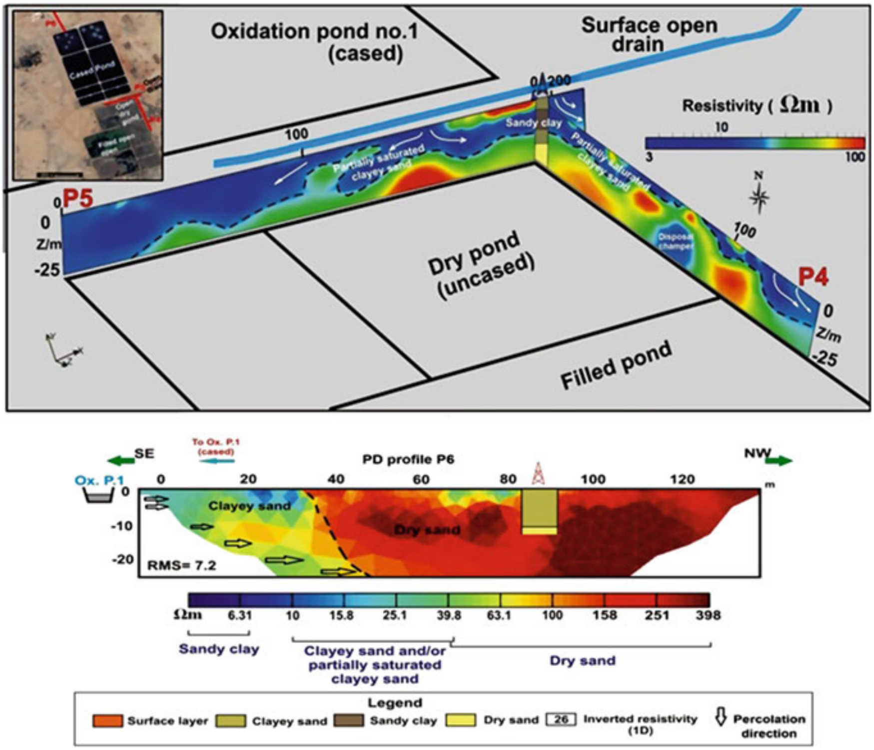

Fig. 4.11 (Top) Fence diagram of 2D inverted profiles (P4 and P5). (Bottom) 2D profile (P6) showing the heterogeneity and wastewater percolation around the oxidation pond at Tenth of Ramadan city, modified after [11]

wastewater) migration can be formed leading to environmental problems, e.g., limestone dissolution and soil water seepage. Furthermore, water-filled fault and fracture zones play a significant role in the structural stability of underground openings and infrastructures such as tunnels. Also, flow of water into tunnels throughout fracture zones can delay construction. Moreover, fractures affect stability, and fluid flows into near-surface structures. Therefore, it is vital to recognize and predict the migration pathways of contaminants/wastewater at the surface or near-surface environment to avoid engineering and environmental hazards.

Along CSD, integration of surface structural measurements and mapping are integrated with DCR surveys to evaluate the near-surface structural conditions including fractures and fault zones. Figure 4.12 shows inversion results of 2D ERTs, which were measured at CSD, considering surface geology. Long fractures (<1 m length) with 0.5 m apertures were observed during field studies. They exhibit lateral lithological discontinuities forming gaps in limestone with clay/sandy clay fillings (Fig. 4.13), which were observed in the central parts of the 2D ERT profile. Also, sinkholes were observed near a fault zone which is formed due to the dissolution of limestone by

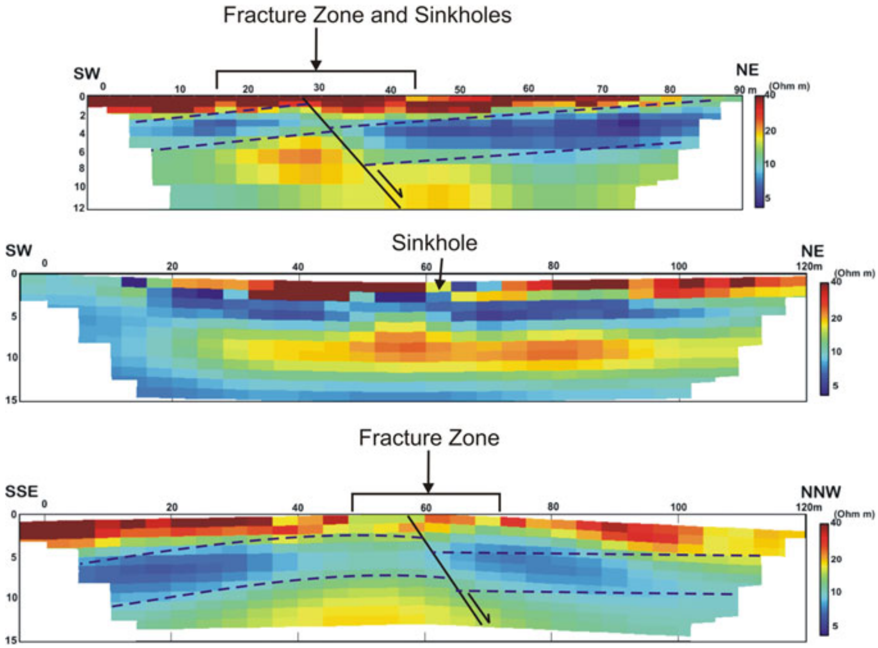

Fig. 4.12 Inversion results of the 2D ERTs representing the subsurface layer distributions, structures and the observed fracture zones and sinkhole location

surface water. Geotechnically, fractures and sinkhole existence can produce natural hazard-prone areas. The integration of surface data with the 2D ERTs shows the effectiveness of applying structural/geophysical strategy to assess the hazards and environmental impact of wastewater in highly fractured limestone rocks at a new urban area.

C Assessment of environmental hazards caused by the radioactive emissions at Central Eastern Desert, Egypt

Recently, the mining industry in Egypt has been characterized by a high rise, through the discovery of many minerals and the development of others. In particular, natural radiation measurements are broadly made at varying sites for clean energy producing, for example, electricity production. Furthermore, aerial surveys were conducted in the vicinity of mineral resources. Despite the importance of radiation development in our national economy, it is a dangerous source to human health and environment. The current case study is considered an example of airborne spectral data in the environmental application. The exposure and dose rates were determined to study the environmental impact of natural radiation and its potential hazards resulted by the anomalous distribution of natural radioelements.

Gabal El-Rubshi area is highly structured and consists of rocks ranging chronically from Precambrian to Quaternary (Fig. 4.14). The ultramafic rocks (serpentines) and

Fig. 4.13 Fractured limestone with wide fracture aperture that is filled with clay

associated derivatives are considered the most ophiolitic sequence units found in the area [19].The most important mineral deposit of considerable value occur in the area is the chromite deposits, which restricted to the upper parts of the serpentines. The study area was secured as a part of an airborne spectrometric and magnetic surveying program did in 1984, by Aero Service Division of Western Geophysical Company, USA. Such surveys were led along parallel NE-SW flight lines with 1 km interval spacing. Meanwhile, the NW-SE tie-lines were flown at 10 km intervals. The obtained airborne gamma-ray spectrometric and magnetic survey data were reduced, gathered and lastly introduced in the form of contour maps.

Potassium in percent (K%), equivalent uranium (eU in ppm) and thorium (eTh in ppm) were detected after applying the most important methods of correction, including background and stripping ones. The average values of radioelement have been converted into environmental units that are expressed as annual efficiencies. The equivalent values of doses of gamma rays in inclination will vary in year (milliseconds/year) according to the relations provided by Atomic Energy Agency [20]. The effective annual equivalent values of the dose are generally low, with an average ranging from 0.2 to 1.1 mSv per year for the central and northern parts of the area. The slightly moderate value is associated with the eastern and western rocks exposed, while the very high rate, with a value range more than 6 mSv per year, is observed at the northwest and southeast directions (Fig. 4.14). Analytic signal (AS) filter was applied to the magnetic data, as it gives a representation of the subsurface structures. According to the directional analysis of mapped faults from AS image, the NW-SE and NE-SW foliation and shear zones are the most frequent and conspicuous in the area.

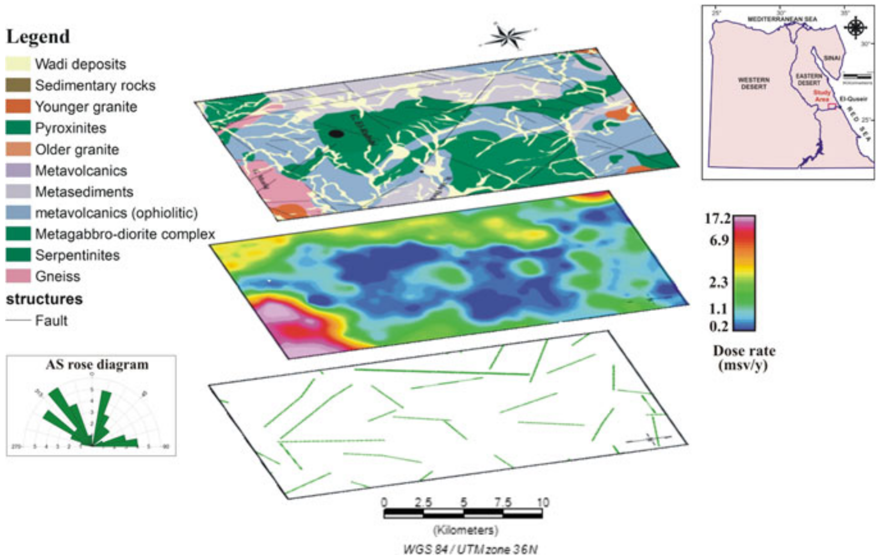

Fig. 4.14 Environmental impact of natural radiation based on dose rate values and subsurface fault map extracted from AS with rose diagram

Based on the results reported in this case history, the investigation site represents the safe area in general and structure features play an essential role in controlling the radioactive mineral accumulation. In contrast, the high levels of the natural gamma-ray radiation in the area should be taken into consideration. Consequently, serious and decisive measures must, therefore, be taken to protect against radiation. The three basic factors used to reduce the external radiation impact are time, distance and shielding. The proper shielding material to use depends on the type of radiation and its energy. These results may be utilized as reference data for proper planning to maintain the health of workers in mining regions.

D Detection and delineation of hydrocarbon leakage of tanks and pipelines

The present case history is an oil-contaminated site near to hydrocarbon storage tanks and pipelines at a coastal area, the northern part of Egypt. Recently, it observed an oil leakage from some parts of storage tanks to the lake close to such tanks. This contamination occurred during the engineering activities of bridge construction around this site. Geologically, the study site is characterized by a sequence of carbonate rocks and shale intercalations. The current research aims to image pollutant movement and delineate the soil-contaminated zones.

An integrative approach of RS and DC resistivity techniques was applied to describe subsurface vertical and lateral inhomogeneities. Here, the RS was used to demonstrate the aerial images to characterize the near-surface changes of materials (dark blue and black patches) related to oil seepage on the ground and water surfaces (Fig. 4.15, top). A suitable geophysical method to image such leakage is

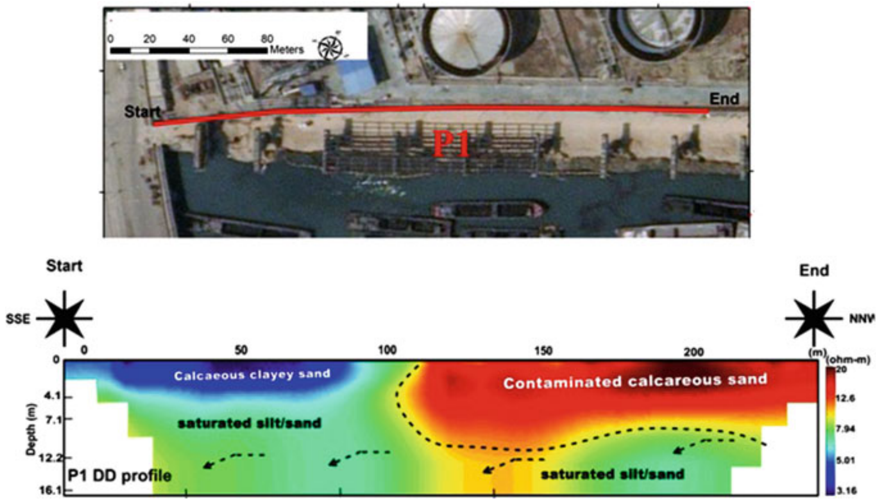

Fig. 4.15 (Top) Landsat image showing the oil tanks and nearby lake. (Bottom) Resistivity tomogram (2D ERT) at an oil-contaminated site showing the subsurface layers and contaminated zone with water flow path

the DC resistivity method. The geophysical 2D survey was carried out perpendicular to oil seepage zone using DD array of 5 m electrode spacing. The measured data were processed and inverted using a conventional inversion method by applying a smoothness-constrained algorithm. Figure 4.15, bottom, shows the tomogram resulting from the inversion process. The inspection of Fig. 4.15, bottom, indicates the oil-contaminated zone related to hydrocarbon leakage of tanks and pipelines. Also, the saltwater intrusion and water flow path are presented. Accordingly, the integration of RS and DC resistivity method can resolve the small-scale oil-contaminated zone with high details. Furthermore, DC resistivity signatures can be indicators of hydrocarbon contaminants and measurements along 2D profiles can detect the movement of contaminant fluids.

4.9 Conclusions and Recommendations

The organic waste contaminants, radioactive emissions and hydrocarbon leakage detection with noninvasive geophysical techniques are very difficult, are not regularly performed and are classically only successfully applying current state-of-the-art techniques. As the first step in waste management system, the current chapter highlighted the importance of an integrative approach for geo-environmental assessment. The present approach combined structural, RS and geophysical data to provide information concerning the geo-environmental assessment. The study showed that RS and GIS could provide a platform of different convergences obtained from multidisciplinary studies. Also, the chapter pointed out that the integration of structural and geophysical data is valuable for detailed geological and structural mapping. Accordingly, the combination of such data in an integrative approach allows us to draw accurate and detailed images of surface and subsurface geological conditions. This integrated approach can be considered as a promising tool to image and evaluate geotechnical and geo-environmental problems related to organic and solid pollutants.

The case histories discussed above indicated that the integration of outcrop and geophysical methods has great importance for the decision-makers in geo-environmental assessment and waste management. Continuing applications of the present approach and more research into the contaminant geophysical properties should result in further successful applications of geophysical techniques to the characterization of organic waste contaminants and hydrocarbon leakage. Accordingly, it is necessary that fund holders and development managers incorporate the present approach into development strategies to avoid many geo-environmental hazards. The present approach introduces recommendations and remedial measures for detection, prediction and prevailing hazards in urban areas and desert lands. The approach could be used to update geo-hazard assessment in desert urban areas once surface and subsurface data become available to be integrated as explained in Fig. 4.9. Furthermore, the suggested approach can be easily used in new urban areas, especially those with limited fund, to develop the geo-environmental and geotechnical assessment. Finally, special attention is required to study the geological/structural conditions and to select the suitable geophysical method based on expert's judgment and considering the study area location.

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Chapter 5
Phytomanagement in Egypt: A Sustainable Approach for Clean Environment Coupled with Meeting Future Energy Demand

Mahmoud Nasr

Abstract In Egypt, the exponential population growth along with the development of industrial and agricultural activities has resulted in several environmental and economic issues. These concerns include soil and water contamination, water scarcity, and insufficient energy supply. This chapter presents the application of biofuel crops as a sustainable, environmental-friendly, and solar-driven approach for remediating the contaminated environment and generating new bioenergy resources. The main phytoremediation processes are (a) phytodegradation: Plants breakdown, transform, and assimilate organic pollutants through enzymatic activities and metabolic mechanisms; (b) phytovolatilization: Plants uptake contaminants from soil, followed by transformation and volatilization into the atmosphere; (c) phytoextraction: Plants absorb metallic and organic substances from soil, which are subsequently translocated, accumulated, and stored in aboveground portions; (d) phytostabilization: Plants minimize the mobility of contaminant via absorption, adsorption, accumulation, and precipitation within the rhizosphere; (e) phytofiltration: Aquatic plants remove pollutants from water mainly via bioadsorption and intracellular accumulation using the root system; and (f) rhizodegradation: Plants and associated microbes in the root zone are integrated to breakdown contaminants in soil. Further, energy can be obtained from harvested plant biomass either by direct combustion or by conversion into solids (e.g., biochar), liquid (bio-oil, biodiesel, or bioethanol), and gas (CH_4 biogas). The advantages of phytomanagement in Egypt are threefold: (a) utilization of large desert and forest areas, (b) provide treated wastewater that can be used for irrigation to prevent water scarcity, and (c) grow biofuel crops (e.g., Jatropha curcas) that can be used for bioenergy production.

Keywords Agricultural biomass residues · Bioenergy crops · Phytoremediation · Soil and water contamination · Water and energy needs

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5.1 Introduction

In Egypt, the expansions of industrialization, urbanization, anthropogenic practices, and agricultural activities have adversely impacted the environmental quality [12]. Effluents from various industrial sources such as mining, batteries, electroplating, tanneries, and textiles have increased the quantities of heavy metals in water bodies [17]. Exposure to toxic metals including lead (Pb), cadmium (Cd), nickel (Ni), mercury (Hg), zinc (Zn), and arsenic (As) is associated with health problems, e.g., skin poisoning and damages of kidneys, liver, and central nervous system [16]. The contamination of soil environments has also ensued due to the unrestricted disposal of domestic sludge and agricultural residues [32]. Moreover, farm runoff comprises surplus levels of pesticides, nitrogen, phosphorus, and organic compounds that can seep into groundwater and increase the risk of crop damage [13]. Accordingly, appropriate soil and water remediation methods should be employed to protect human health, vegetation, food chain, and animals.

Environmental remediation has been recognized as a clean, eco-friendly, and cost-effective method for the protection of soil and water environmental systems [7]. The cost of soil remediation can reach up to \$500 per ton of soil or \$100 per m^2 of a contaminated land area, and the period required for complete remediation can be within 15 years [24]. Remediation includes physical and chemical methods such as thermal deposition, soil replacement, immobilization, electrokinetic, excavation, and soil washing [5, 26]. Although the physicochemical remediation techniques are well-established, they may deteriorate the properties and structure of soils in the long term [14, 24]. Alternatively, biological remediation, also known as bioremediation, has been applied using plants and microorganisms to overcome the drawbacks of other conventional treatment methods [35]. This biological activity is used to remove toxic contaminants, heavy metals, and multiple pollutants from the environment [43]. Bioremediation techniques include phytoremediation, bioaugmentation, phycoremediation, biostimulation, and mycoremediation [42].

Among the biological remediation approaches, phytoremediation, which is the utilization of plant-based technologies for cleaning up the contaminated soil and water, is the most innovative technique that retains high public acceptance [46]. The term "phytoremediation" is composed of "phyto" that is related to plant and "remedium" that is equivalent to restore, reclaim, or cleanup. Phytoremediation is safe, solar energy-dependent, and green technology that can preserve the soil physical and chemical properties [24]. Phytoremediation can deal with a wide range of pollutants such as inorganic and organic substances, metalloids, and non-biodegradable matters [36]. The removal mechanisms of contaminants via phytoremediation include phytoextraction, phytoaccumulation, phytostabilization, phytodegradation, phytovolatilization, phytomining, and phytodesalination [2, 15]. Moreover, the efficiency of phytoremediation can be improved by the augmentation of microbial communities in the rhizoplane, i.e., a mechanism known as rhizoremediation [37]. Microbes can accumulate on the plant roots and stimulate the plant tolerance toward various environmental stresses [1]. The previously investigated plant species for phytoremediation are *Plectranthus amboinicus*, *Callitriche cophocarpa*, *Eichhornia crassipes*, *Carex pendula*, *Azolla pinnata*, and *Phaseolus vulgaris*. The advantages of phytoremediation include lower cost compared to conventional physicochemical treatment methods, small amounts of sludge, simplicity in operation, and the improvement of air quality due to the increased green area [25].

After phytoremediation, the harvestable portions of plants may hold vast quantities of heavy metals [7]. The phytomanagement of this large quantity of biomass requires considerable attention to avoid the negative impacts of pollutants on the receiving environment [11]. An integration of phytoremediation with bioenergy production is considered one of the most viable solutions for the management of harvested biomass from polluted sites [14]. For example, Zhao et al. [48] reported that plant biomass could afford about 13–15% of the global energy demand. In this context, the use of energy crops for phytoremediation can contribute to the fulfillment of energy demand using a renewable, green, and carbon-neutral biomass source [8]. The broadly recognized crops for the potential application of phytoremediation energy production are *Miscanthus giganteus*, *Populus* spp., *Ricinus communis*, and *Jatropha curcas* [36].

Hence, this chapter represents the utilization of various plant species for the remediation of contaminated soil and water environmental systems. Several phytoremediation mechanisms along with the advantages and drawbacks of each technique are explored. The chapter also discusses the strategies used to involve the pollutant-loaded plant wastes for bioenergy production. The proposed waste-to-energy conversions are direct combustion, gasification, pyrolysis, and anaerobic digestion. These objectives are comprehensively illustrated along with previous studies reported in the literature. Recommendations for future perspectives in the field of plant application for a clean environment and energy supply are also demonstrated.

5.2 Soil and Water Pollution

Recently, the application of heavy metals in anthropogenic practices and industrial processes has released high amounts of toxic elements into soil and water [7]. Moreover, some metal-containing compounds are used for domestic and agricultural activities, which consequently pose detrimental impacts to the receiving environment [24]. In addition, smelting, coal combustion, and cosmetic, medical, and pharmaceutical wastes lead to the generation of hazardous substances [29]. Farm operations are associated with the production of crop residues, animal dung, cattle manure, and agricultural wastewater [43]. Anthropogenic sources including vehicle emissions, waste incinerators, wood burning, and fuel oil and coal combustions, as well as natural sources such as forest fires and volcanic eruptions, also deteriorate the air quality [44].

These elements can enter the body through the food chain and pose severe implications to the human health such as neurobehavioral disorders, chronic anemia, cognitive impairment, and teratogenic and mutagenic effects [12]; Gar Alalm and

Nasr [13]. The accumulation of pollutant species in the human body can also cause cardiovascular disease, cancer, and damages of bones, nervous system, kidneys, and brain [45]. The contamination of water bodies by organic wastes and nutrient fertilizers leads to eutrophication, a creation of dense algal blooms, dissolved oxygen depletion, and aquatic organisms' damage [37]. Pollutants can shift the function, diversity, and activity of soil microbial population and inhibit the plant metabolism and growth [2]. Accordingly, the minimization of these environmental and health risks is an essential and critical task.

5.3 Soil and Water Treatment

The treatment methods of water can be classified into three principal groups, i.e., physical, chemical, and biological technologies [12]. Physical treatment methods are mainly used for the separation of solid particles without altering either the chemical or biological water characteristics. They include equalization, screening, grit removal, degasification, centrifugation, membrane filtration, air stripping, sedimentation (or clarification), and flotation and skimming processes.

Chemical water treatment describes the addition of chemical material (e.g., Fenton's reagent and alum salt) to the water to improve pollutants removal. The commonly used chemical processes are coagulation/flocculation, chlorination, ozonation, and neutralization. Some processes such as adsorption and ion exchange can be considered both physical and chemical in nature [38].

Biological wastewater treatment involves microbial activities, i.e., mainly bacterial cultures, to convert organic compounds into stable end products [4]. Based on the dissolved oxygen availability, the biological treatment methods can be divided into aerobic treatment (e.g., activated sludge process, trickling filter, and oxidation ditch) and anaerobic activities in digesters, fermenters, and septic tanks [30].

Soil treatment is classified into in situ and ex situ techniques [15]. According to Liu et al. [24], in situ technologies include biological treatment (biostimulation, bioaugmentation, phytoremediation, and natural attenuation), physical methods (e.g., surface capping and encapsulation), and chemical treatment (e.g., soil flushing and immobilization), whereas ex situ technologies compress physical treatment (e.g., landfilling), chemical treatment (e.g., solidification and soil washing), and thermal treatment (e.g., vitrification).

The term "biostimulation" is used to describe the addition of essential electron acceptors such as nutrients, oxygen, or carbon to improve the microbial growth and activity [1]. Bioaugmentation is the injection of soil by specific microbial species that can stimulate the indigenous populations to degrade pollutants of concern (e.g., the addition of hydrocarbon-degrading microorganisms). Surface capping attempts to preserve the contaminated soil with a stable and protective barrier that limits the migration of pollutants to surface water and groundwater. Surface capping is suitable only for dry climates as the barriers cannot sustain precipitations and fluctuations in atmospheric temperature. The extraction of toxic elements (e.g., heavy metals) from contaminated soil by injecting fluid or other appropriate aqueous solution through the soil is known as soil flushing [5]. Solidification, also known as "stabilization," involves physical and chemical mechanisms to reduce the solubility of hazardous components via immobilization and isolation. Vitrification is able to separate organic compounds and immobilize heavy metals from soil via the formation of a glassy matrix that can entrap the waste [22]. Most of the physical and chemical treatment methods are expensive and suitable for small areas, and they may cause disturbance to the soil properties and microflora. Moreover, they require intensive manpower and controlled environmental conditions.

Among the aforementioned methods, this chapter focuses on the application of natural or genetically adapted plants (i.e., phytoremediation) for the treatment of soil and water environmental systems.

5.4 Phytoremediation

Phytoremediation is an effective approach that can reduce the negative impacts of toxic contaminants on the environment and ecosystem health [19]. The objectives of phytoremediation are threefold [5, 14]: (a) removal of organic and inorganic pollutants from contaminated soil and water, (b) extraction of heavy metals for recycling applications, and (c) conserve soil properties and fertility for sustainable management of unused sites. The phytoremediation cost can increase from $25 to $100 per ton of contaminated soil and $0.60–$1.59 per m^3 of treated water [9]. Readily biodegradable compounds can be eliminated via plant enzymatic activities and rhizobacteria, whereas non-biodegradable pollutants are removed via accumulation, stabilization, transportation, and extraction. These mechanisms can be summarized as follows:

5.4.1 Phytodegradation (Phytotransformation)

The degradation and breakdown of organic xenobiotics via exogenous secretions (e.g., enzymatic activities) within plant tissues are recognized as phytodegradation [31]. This process can also be used to describe the transformation of highly toxic pollutants to less toxic forms such as the conversion of Cr(VI) to Cr(III). Before phytodegradation, organic contaminants should be efficiently captured from the soil and accumulated by plant roots. Hence, soil amendments (i.e., chelating agents) can be used to break the binding bonds between soil particles and organics [22]. The removal mechanisms of phytodegradation are influenced by the metabolic processes and enzymatic activities of plants. Some organic contaminants are converted into simpler compounds and incorporated into tissues to improve plant growth, while others are completely converted into H_2O and CO_2. Phytotransformation is applicable for the removal of less toxic elements including herbicides, landfill leachates, petrochemical, ammunition wastes, and agricultural chemicals. However, this process is limited by the transfer of contaminants from soil to animals through the food chain.

5.4.2 Phytoextraction

The initial stage of phytoextraction aims at cleaning the contaminated soil via the absorption and sequestration of toxins by plant roots. This phase is followed by translocation and accumulation in the harvestable portions (i.e., plant shoots) via the transpiration flow of water [46]. The plant used for phytoextraction should be characterized by rapid growth rates, intensive biomass production, deep and diverse root systems, and high absorption and accumulation capacities.

According to Baker and Brooks [6], hyperaccumulators are able to accumulate over 100 mg Cd/kg DW, 1000 mg of Ni, Cu, or Pb per kg DW, or 10,000 mg of Zn or Mn per kg DW in their shoots. The most common families of hyperaccumulators are *Scrophulariaceae*, *Asteraceae*, *Brassicaceae*, *Fabaceae*, *Euphorbiaceae*, and *Lamiaceae*. These families can adapt to various environmental conditions, resist pathogens and insect herbivores, and tolerate high toxic levels.

Chelating agents are used to activate the bioavailability of heavy metals in the soil and form more soluble complexes with the metal ions, leading to enhance the root absorption capabilities. However, the slow decomposition of synthetic chelating agents may adversely impact the soil microorganisms and groundwater quality.

5.4.3 Phytostabilization

Phytostabilization is also recognized as phytodeposition and phytosequestration. Phytostabilization employs the utilization of plant roots to reduce the pollutants mobility and bioavailability in the rhizoplane of contaminated soil [23]. This trend attempts to minimize the leaching of toxicants to groundwater or transport of inorganic contaminants into precipitation water. The removal of contaminants via phytostabilization involves multiple mechanisms such as adsorption onto root surface, absorption and accumulation by plant roots, and precipitation within the root zone. Microorganisms located in rhizosphere can also contribute to phytostabilization through the conversion of organic contaminants from the soluble state to the non-toxic forms [25]. Phytostabilization depends on (a) plant transpiration and tolerance to high levels of contaminants, (b) root growth, (c) structure and properties of soil, and (d) type and concentration of trace elements in soil. Phytostabilization can be improved by using organic and inorganic soil amendments (i.e., immobilizing agents), i.e., a process known as aided phytostabilization.

5.4.4 Phytovolatilization

In phytovolatilization, pollutants are captured from soil via the root system, converted to a volatile form, and then released from the aerial plant parts to the atmosphere through transpiration [37]. Contaminants may also be degraded during their travel from the roots to the leaves along the plant's vascular system. This process is suitable for the removal of organic compounds and certain heavy metals such as Se and Hg.

5.4.5 Phytofiltration

The sequestration of trace metals and impurities from contaminated water by plants is known as phytofiltration. Phytofiltration by plant roots is known as rhizofiltration, whereas the applications of seedlings and excised plant shoots for phytoremediation are termed "blastofiltration" and "caulofiltration," respectively. The removal mechanisms of phytofiltration include absorption, precipitation, and subsequent accumulation in plant parts.

5.4.6 Phytomining

Phytomining is used to extract heavy metals such as Ni, Au, and Co using plants from low profitable ores that can take about 10–100 years for ecological restoration [33]. The harvested biomass is then subjected to thermal treatment (e.g., combustion) to produce a commercial bio-ore. The advantages of phytomining include reclamation of several contaminated sites, obtaining high-value elements, and minimizing the dispersal of metal mining wastes in groundwater. Phytomining is controlled by root depth, soil acidity, climatic conditions, the solubility of heavy metals, and the supplement of chelating agents.

5.4.7 Rhizodegradation

Rhizodegradation is the use of plant roots and associated rhizobacteria to degrade organic xenobiotic via enzymatic activities. This process is also known as plant-assisted bioremediation or enhanced rhizosphere biodegradation. Plants attempt to manipulate the physicochemical and biological conditions of the rhizosphere and increase the number of microbes, whereas the complex ecosystems of microorganisms can consume and digest organic compounds [1]. This plant-microbe integration results in a significant reduction of organic pollutants.

Microorganisms (e.g., bacteria, protozoa, fungi, and algae) can develop and expand as a biofilm over the plant roots and contribute to soil remediation through direct and indirect traits [31]. The defense mechanisms of microbes against toxic elements include enzymatic detoxification, extracellular polysaccharides (EPS) sequestration, metal exclusion, and the use of efflux pumps [2].

Bacteria can directly transform heavy metals into bioavailable and soluble forms via acidification (i.e., generating citric, gluconic, and oxalic acids), redox changes, and release of chelating agents. Microbes can also produce biosurfactants that form complexes with heavy metals or attain biomethylation that causes metal volatilization [22]. The converted elements (e.g., Fe(III) to Fe(II), Mn(IV) to Mn(II), and Hg(II) to Hg(0)) are then readily taken up by plants as nutrients.

Microbes can indirectly promote phytoremediation via improving plant growth, inhibiting plant infection by phytopathogens, adapting root morphology, and enhancing plant metal tolerance [26]. These trends are attained through the production of pathogen-depressing substances (e.g., siderophores), 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase, and indole-3-acetic acid (IAA). In addition, bacterial species encourage plant growth through some routes such as iron sequestration, nitrogen fixation (diazotrophs), and phosphorus solubilization [44]. Rhizosphere microorganisms can also minimize the noxious impacts of metals on plants, and they can volatilize, transform, and degrade several contaminants (e.g., Cr^{6+} to Cr^{3+}).

5.5 Harvested Biomass for Energy Production

Energy demand in Egypt has recently increased due to the developments of industrial, agricultural, and commercial sectors. The utilization of fossil-based fuels as an energy source has emitted significant amounts of CO_2 and greenhouse gases to the atmosphere, leading to climate change. Moreover, the current generations of coal, oil, and diesel are inadequate to cope with the growing energy demand. Alternatively, biomass can be used as a renewable and sustainable solution for clean bioenergy production [29]. Some crops are cultivated on contaminated lands for the purposes of soil remediation and bioenergy production. For example, Edrisi et al. [10] reviewed the recent applications of *Jatropha curcas* L. as a renewable source of biofuels for phytoremediation of pesticide and heavy metals and restoration of contaminated and degraded lands. Jatropha plant, known as an energy crop, can provide various environmental, economic, and social benefits. Shaoa and Chuc [40] reported several plant species that contain oil content over 40% in seeds and other major woody oil plants that can be used for biofuel production. Some tree species such as willow, poplar, and jatropha have been used as energy crops due to their ability to (a) thrive in severely contaminated soils, (b) eliminate various types of heavy metals, (c) enhance the soil quality and microbial population in rhizosphere, and (d) provide beneficial products such as charcoal, fiber, wood, bioethanol, and biodiesel.

The various energy recovery techniques after phytoremediation can be summarized as follows:

5.5.1 Direct Combustion

Direct combustion is a well-established technology for the conversion of plant biomass to heat that can be utilized for industrial processes [34]. The combustion process is carried out by burning the biomass fuel at a temperature range of 800–1200 °C in an excess air environment, i.e., complete oxidation. The remaining solids after combustion are known as charcoal, whereas tars represent the released gasses and liquids. The combustion of plant biomass can occur in stoves, boilers, or furnaces. The combustion process involves sequential phases of moisture removal (drying), pyrolysis, the formation of char and volatile gases, complete flame combustion of volatile gases under sufficient oxygen, and burning of solid char.

Complete combustion converts the biomass into mainly CO_2 and H_2O. The purposes of combustion are twofold: (a) production of steam, which can be converted to electricity by a steam turbine, and (b) generation of hot air or hot water through a heat exchanger. The main drawback of combustion is the release of gaseous carbonaceous compounds, volatile inorganic species, ash particles, and tarry substances. The increase in ash deposition may reduce the burner efficiency, damage the burner, and cause maintenance issues.

5.5.2 Gasification

Gasification is the partial oxidation of biomass using insufficient oxygen or steam [39]. Gasification occurs at a temperature range lower than that of combustion, resulting in the generation of heat, combustible gas, volatiles, and ash. Gasification occurs through four serial stages of drying (obtain dry biomass at 100–150 °C), pyrolysis (heat without air at 200–500 °C to form tar and char), oxidation/combustion (add air at 800–1200 °C to burn and crack tar gases), and reduction (convert charcoal to syngas gas at 650–900 °C). The main stage of gasification is the vaporization of volatile components under a deprived oxygen environment to obtain a mixture of tar, charcoal, CO, CO_2, H_2, and H_2O. Further, the remaining char product is converted to a clean-burning fuel gas by reactions with oxygen (combustion) or steam (classic gasification) at elevated temperature values. The advantages of gasification are threefold: (a) Obtain purified syngas that can be converted into ethanol and chemical feedstock for industrial applications, (b) the produced gas can be converted into electricity by fuel cells, gas turbines, or other engines, and (c) it inhibits the generation of some pollutants such as particulates, SO_x, and NO_x compared to complete combustion.

5.5.3 Pyrolysis

Pyrolysis is a thermal treatment of biomass in the lack of air/oxygen at a temperature of 350–600 °C [21]. The main products of pyrolysis are liquid fuel (e.g., bio-oil), charcoal, heat, and gases including CO, CO_2, H_2, and CH_4. Slow pyrolysis attempts to generate tar and char as main products, whereas fast pyrolysis is principally used to obtain bio-oil and gas. Biochar is a fixed carbon constituent that can be used as soil amendment or for the preparation of activated carbon. Bio-oils are derived from the volatile portion of biomass, and they can be refined into transportation fuels. The advantages of pyrolysis are threefold: (a) waste reduction, clean up, and management; (b) use of simple and inexpensive technology; and (c) production of energy to fulfill domestic needs.

5.5.4 Biological Conversion

The conversion/breakdown of organic biomass to biogas (CH_4) via microbiological activities under a deprived oxygen environment is known as anaerobic digestion [28]. The main products of anaerobic digestion are threefold: (a) biogas used to generate electricity or heat, (b) liquor applied as a raw liquid fertilizer for farmlands, and (c) rich-nutrient fiber employed as a soil conditioner. The advantages of anaerobic digestion include reduction of wastes and pathogens, generation of high-quality and renewable sources of energy, and application of "biomass-to-biogas" concept. However, the application of anaerobic digestion for energy recovery after phytoremediation is technically challenging because the harvested biomass is heavily hampered by toxicants, trace elements, and heavy metals, which can deactivate the bacterial activities.

Four main bacterial groups are used to complete the anaerobic digestion process:

Group I, namely hydrolytic bacteria, which converts the complex organic biopolymers into monomers. For example:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2$$

Group II, namely acidogenic bacteria, which converts large organic polymers to amino acids, sugars, and volatile fatty acid. For example:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$$
$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$$
$$C_6H_{12}O_6 \rightarrow 3CH_3COOH$$

Group III, namely acetogenic bacteria, which converts intermediary products such as volatile fatty acids into acetic acid and hydrogen. This stage can be used to obtain hydrogen gas via dark- or photo-fermentation processes [30]. For example:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$$
$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 3H_2 + H^-$$

Group IV, namely methanogenic bacteria, which converts either hydrogen to methane or acetate to methane. For example:

$$CH_3COOH \rightarrow CH_4 + CO_2$$
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

5.5.5 Bioenergy Plants for Phytoremediation: Case Studies

Recently, previous studies have investigated the application of energy crops for detoxifying the contaminated soil and water environments. These studies can be discussed as follows:

Van Ginneken et al. [45] studied the utilization of chelating agents to enhance the bioavailability of heavy metals in soil for a better phytoremediation process. The harvested biomass plants were subjected to various energy recovery approaches such as gasification, incineration, and anaerobic digestion. The phytoremediation capacity and biodiesel production were reviewed regarding the crops of wheat, rapeseed, and maize.

Jamil et al. [20] investigated the application of *Jatropha curcas* as a biofuel crop for the phytoremediation of fly ash landfills containing various heavy metals (e.g., Mn, Cr, Fe, Al, and Cu). The use of ethylene diamine tetra acetic acid (EDTA) facilitated the plant uptake capacities, in which the metal removal efficiencies at EDTA of 0.0, 0.1, and 0.3 g/kg were 0.37, 0.55, and 0.64%, respectively, after 60 days of exposure. At EDTA of 0.3 g/kg, the metal removal efficiencies enhanced from 0.64% for 100% fly ash soil to 3.64% for 50% fly ash + 50% garden soil, suggesting the positive impact of nutrients availability on the plant performance. The removal mechanisms were phytoextraction (i.e., extraction from soil and concentration in the harvestable parts) and phytostabilization (i.e., limit the bioavailability of metals in the rhizosphere).

Meers et al. [29] applied a bioenergy crop of *Zea mays* for the remediation of historically contaminated soils. The concentrations of heavy metals in the whole shoot were (in mg/kg): 0.58–0.68 for Cd, 2.24–3.09 for Pb, and 124–191 for Zn. The phytoextraction mechanism (absorption of metals followed by translocation) contributed to the remediation of heavy metal-contaminated soil. The harvested biomass could be subjected to anaerobic digestion under a mesophilic condition to produce biogas and digestate, leading to the generation of 30,000–42,000 kW/ha/year as electrical and thermal renewable energy.

Huang et al. [19] examined the ability of bioenergy crop *Ricinus communis* to uptake Cd and dichlorodiphenyltrichloroethane (DDT) from a co-contaminated soil. The concentrations of Cd and DDT (in mg/kg DW), respectively, recorded 1.22 and 0.37 in the leaf, 2.27 and 0.43 in the stem, and 37.63 and 70.51 in the root. The removal mechanisms were phytoextraction, accumulation, biodegradation, and absorption.

Liu et al. [23] used constructed wetlands to remediate domestic wastewater and produce cellulosic biofuel. The study depicted that the plot of bioenergy production against nitrogen supply obtained a logarithmic curve, suggesting that the optimum nitrogen load should be identified to achieve the highest biofuel production. Moreover, the mean biofuel production of surface flow constructed wetland was lower than that of the subsurface flow hydraulic pattern. The maximum biofuel production was obtained from *Arundo donax* (1836 GJ/ha/year) followed by *Pennisetum purpureum* (1628 GJ/ha/year).

Zhao et al. [48] investigated the growth of bioenergy plants, viz. *Acorus calamus*, *Thalia dealbata*, and *Zizania caduciflora*, in hypereutrophic water. The plants were able to eliminate nutrients of 50.3% total nitrogen, 59.4% ammonium nitrogen, and 86.5% total phosphorus with high biomass productions during 16 days. Moreover, the aboveground tissues of most plant species contained neutral detergent fiber of 649–750 g/kg and acid detergent fiber of 362–412 g/kg, suggesting the usability of the investigated species for bioenergy feedstock.

Abhilash et al. [2] used a biodiesel plant *Jatropha curcas* L. for the remediation of garden soil subjected to different spiked lindane concentrations. After 300 days, the accumulation of lindane in Jatropha increased from 5.42 to 20.85 μg/g at elevating the lindane concentration from 5 to 20 mg/kg, respectively. The removal mechanism focused on the rhizoremediation potential of Jatropha, in which the maximum accumulation was observed in the root subsequently the stem and the leaf.

Delplanque et al. [8] investigated the application of *Salix viminalis* "Tora" for the phytoremediation of metal-contaminated dredged sediment landfill site. Based on a soil depth of 50 cm, the duration required to decrease the concentration of Cd from 2.39 to 2.00 mg/kg DW, if both stems and leaves were harvested, would be 19 years. Moreover, the bioconcentration factors of stems and leaves, respectively, were 3.0 and 5.0 for Cd and 1.3 and 1.8 for Zn, implying that *Salix* "Tora" tended to accumulate Cd more than Zn. The removal mechanism was phytoextraction, which attempted to transfer heavy metals from soils to the harvestable portions of the plant. Further, the harvested biomass was subjected to a thermal treatment at 900–1000 °C and 40 kW to determine the distribution of metals in the final products of the combustion process. The concentrations of metals in bottom ash and flue gas, respectively, were 0.06 and 6.3 mg of Cd per kg of stems burnt, whereas they recorded 15 and 358 mg of Zn per kg of stems burnt. The study recommendations were twofold: (a) the application of efficient filters to obtain metal-free ash and avoid air pollution and (b) the addition of coal or other fuel products to the plant biomass in a co-combustion process to develop a sufficient source of energy.

Smith et al. [41] used remediated brownfield site containing *Panicum virgatum* L., *Glycine Max* (L.) Merr., *Helianthus annuus* L., and *Brassica napus* L. var. *napus* for bioenergy production. The study depicted that brownfields could generate total oil, fatty acid methyl ester, and crystalline cellulose approximately similar to those produced from non-contaminated agricultural lands. Moreover, the bioenergy crop feedstock contained no traces of contaminant, suggesting the applicability of fuel combustion and conversion.

Elhawat et al. [11] investigated the removal of Cu from the soil by bioenergy plant of *Arundo donax* L. and the suitability of biomass production in Cu-contaminated soils. The plant could grow in soil that contains a Cu concentration of 10 mg/L without foliar Cu toxicity symptoms. Moreover, approximately 45% of the removed Cu was detected in the root system, suggesting that transportation, concentration, and accumulation contributed to the removal mechanisms. The obtained biomass could be used for the production of bioethanol and energy.

5.6 Phytomanagement in Egypt

Egypt's quota of water from the Nile River is fixed at 55.5×10^9 m^3 per year, which delivers the major portion (about 97%) of the country's freshwater supply [47]. In addition, over 80% of the water supply is utilized in the agricultural sector with a cultivated area of about 3.5×10^6 ha, equivalent to 3.5% of Egypt's entire land. The irrigated, reclaimed for irrigation, and rain-fed farmlands are (in million hectares): 2.4, 1.0, and 0.1, respectively. Moreover, Egypt holds 4×10^6 ha of rangelands, i.e., 2.3×10^6 ha in the northwest coast, 1.1×10^6 ha in Sinai Peninsula, and 0.6×10^6 ha in Halayeb–Shalateen Triangle [47]. It has been reported that the dependence on the Nile River to cope with the increasing water demand would cause severe depletion in the freshwater availability. The total amount of wastewater in Egypt is reported as 7.3×10^9 m^3 per year, and about 50% of this amount is currently treated [18]. Hence, new strategies should be developed to find appropriate non-conventional water resources such as treated wastewater that can fulfill the future water demands.

In parallel, the gap between production and consumption of energy has sharply enlarged due to exponential population growth, as well as agricultural and industrial activities. The electricity consumption in Egypt is increasing by 6% per year, in which greater than 90% of the electricity is obtained from fossil fuel sources (i.e., mainly natural gas). Other fossil-based fuels such as petroleum, heavy oils, and coal are also used. By 2020, Egypt attempts to generate 20% of the electricity requirements from renewable sources of energy, which will decrease the dependence on fossil fuels along with the reduction in CO_2 emissions and air pollution [27]. By 2052, it is expected that the installed power supply projects will provide 132 GW compared to 17 GW in 2004 [1]. Abdulrahman and Huisingh [1] reported that, in Egypt, the application of combustion, co-combustion (i.e., the addition of a biomass source to fossil fuel during combustion), and gasification would be reliable options for the conversion of discarded agricultural wastes into energy. The waste-to-energy route of about 15×10^6 tons of agricultural residues per year can generate 1×10^6 tons of diesel fuel and 7×10^6 of urea for fertilizers.

Based on the aforementioned givens, phytomanagement using biofuel crops would be a viable strategy for water and soil remediation in addition to renewable energy production. Moreover, the energy crops can be cultivated using treated wastewater as they are non-edible plants. This pattern would overcome Egypt's water security issue. In Egypt, plant species of *Pinus caribbea* var. *hondurensis*, *Pinus caribbea* var. *bahamensis*, *Pinus eliottii* var. *densa*, *Pinus merkusii*, and *Gmelina arborea* can be used as firewood for bioenergy, whereas *Eucalyptus citriodora* is considered a biomass source for oils [47]. Moreover, *Jatropha curcas* is a biofuel plant species that can grow successfully under Egypt's climate (i.e., hot and dry) and limited water conditions [3]. In addition, *Jatropha* can be applied in the Egyptian desert and remote areas as a promising source of biodiesel to solve the challenges of energy requirements. Hegazy [18] reviewed the use of jatropha plantations for the treatment of wastewater from residential cities and the subsequent reuse of treated water in irrigation practices.

5.7 Summary

This chapter presents the dual application of bioenergy plants to detoxify polluted sites (phytoremediation) and to derive beneficial phytoproducts such as bioethanol, bio-oil, fiber, wood, charcoal, and biogas. Plant-based technology is used to remediate the soil and water environments, in which organic matters are removed via phytotransformation, phytostabilization, and phytodegradation mechanisms, whereas trace elements are eliminated via phytofiltration, phytoaccumulation, phytoextraction, and phytovolatilization routes. Rhizobacteria can accumulate on the plant root surface and contribute to soil remediation through multiple direct and indirect traits. The harvested plant portions can be employed to produce energy through complete combustion, gasification, pyrolysis, or anaerobic digestion technologies. This phytomanagement approach can be applied in Egypt to cope with increased pollution and energy demands. Future studies should be conducted to ensure the safety and sustainability of the integrated phytoremediation and bioenergy production systems. Moreover, genetic engineering and biotechnological tools should be used to screen new bioenergy crops that have the ability to thrive in the severe environment, capture and accumulate elevated amounts of contaminants, and attain high biomass production and growth rates. The interaction between plant, microbes, soil particles, and heavy metals in the rhizosphere should be completely defined.

5.8 Recommendations

Although phytoremediation is an attractive and well-established option for contaminated soil remediation, it has some challenges that should be considered for future studies:

- The completion of the soil remediation process requires an extended period (i.e., several years or decades).
- Some metal accumulator plants are limited by low biomass yields and slow growth rates in highly contaminated soils, and they may affect the indigenous microbial diversity.
- The climatic and weather conditions in tropical and sub-tropical regions can deactivate the plant enzymatic activities due to pests and disease attack.
- The harvested plants are considered an unsafe waste that needs adequate and correct disposal method, i.e., that is to avoid the transfer of toxicants into the food chain.
- The cultivation of energy crops (such as jatropha) to generate adequate amounts of biofuels requires sufficient land areas.
- Bioenergy crops should be selected based on their abilities to tolerate, resist, and accumulate high levels and several types of pollutants.
- The cultivated plants should not compete with food crops for the available resources, i.e., nutrients, water, and land.
- The harvestable portion of plant biomass should be adequately handled, stored, and treated.
- Thermal treatment (e.g., combustion) of plant biomass should be performed under controlled conditions, as well as with safe handling and storage of ash products.
- Socioeconomic, environmental, and commercial feasibilities of phytoremediation in combination with biofuel production should be carefully investigated.
- Comprehensive risk assessment studies should be conducted to ensure the safety of farmers, stakeholders, and participants, and to protect the local plant diversity.
- A complete survey on oil plants of Egypt should be conducted, including genetic classifications, methods of collection, treatment, and storage, biological characteristics, economic and ecological benefits, and research experience exchange.

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Chapter 6
The Technical Efficiency of Organic Herbs: The Case of Egypt

Fadi Abdelradi

Abstract The main purpose of this study is to compare the efficiency ratings of organic and conventional herbs and spices farms in the Egyptian delta. To do so, we use stochastic production frontier (SPF) analysis with a Cobb–Douglas stochastic frontier model as a functional form specification for the data. Additionally, we study the factors affecting technical efficiency scores reflecting farmer and farm characteristics (i.e., farmer experience, type of soil and irrigation, location in different governorates as an indicator of being located in a less favored area). Computing output elasticity of different inputs assesses productivity differences between both agricultural practices. The analysis adopts cross-sectional, farm-level data collected from a random sample of 232 (135 organic and 97 conventional) farms that specialize in herbs and spices. Output elasticities of different inputs show that organic farms exhibit higher output elasticities than conventional farms. Labor and area are found to be the most productive factors in organic farming. Organic farmers, on average, are more technically efficient than their conventional counterparts (efficiency ratings are approximately 0.75 and 0.91, respectively). Hence, the results suggest that, by using available resources more efficiently and without changing current technology, organic (conventional) farms can increase their output by about 9% (25%). Concerning the factors influencing technical efficiency, they are found to be relevant.

Keywords Technical efficiency · Stochastic frontier analysis · Egypt · Organic farms

6.1 Introduction

Herbs and spices (H&S) are commonly used as a flavor for food and medicinal purposes as well. There are many similarities between H&S. The main difference between a herb and a spice is from where it is obtained on a plant. Herbs usually come from the leafy part of a plant; spices can be obtained from seeds, roots, or some

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other vegetative substance. Herbs have more uses than spices. For instance, herbs are used more often than spices for medicinal use, fragrance, cosmetics, and flavoring. There are many H&S produced for many growing markets. H&S are a minor but important constituent, increasing a little the cost of the food in which they are used. Demand is relatively inelastic to price changes [11, 41].

In 2014, the EU imports of H&S reached 533 thousand tons with a value of €1.9 billion. The volume of imports increased on average by 3.8% per year between 2010 and 2014, and the imports value has increased by 10% per year. Western Europe is considered the largest consumer of H&S followed by Eastern Europe; UK, Germany, Romania, and Hungary are the largest consumers of H&S for the period 2010–2013, respectively. Imports from developing countries reached 302 thousand tons, which represents 57% of total EU with the largest importers Netherlands, Germany, UK, and Spain, respectively [11]. Developing countries are the source of almost all spices traded in the EU, and after importing, there is a substantial intra-EU trade for these products. The main products imported from developing countries were capsicums (25% of imported volume), ginger 23%, and pepper 21%. Spices prices imported from developing countries increased on average by 6.8% per year for the period 2010 and 2014. The prices for different products increased by vanilla (24% per year), pepper 20%, cloves 20%, and cinnamon 10%. The overall upward price trend is due to the growing global demand [11]. Imports of organic H&S are growing rapidly in the EU for the benefits of such a production system.

Conventional intensive agricultural systems have caused several negative impacts are, just a few examples, on the environment, humans, pollution of underground and surface water, loss of biodiversity, or overutilization of natural resources. Societal concerns regarding the negative externalities caused by conventional agriculture have been growing. Also, the growing consumer awareness concerning the consequences of food choices on their health and the environment. As a result, attention in environmentally friendly agricultural practices has also been growing. Organic farming that replaces chemical inputs with organic fertilizers and non-chemical crop protection inputs has received substantial attention worldwide.

The objective of this chapter is to compare the technical efficiency (TE) between organic and conventional farming herbs and spices farms in Egypt using the stochastic production frontier (SPF) methodology. The contribution of this work is twofold: First, it focuses on the Egyptian agricultural farming; in contrast to the predominant literature, developing countries have not received much attention. Second, despite the current relevant increase in organic farming in Egypt, the literature on the TE of organic farming is scarce. This chapter contributes to the scarce literature on organic farming in Egypt by carrying out a comparative study of TE scores for organic and conventional herbs and spices farms. Assessing technical efficiency scores helps in identifying whether economic agents use their resources optimally to achieve the production objectives.

6.2 State-of-the-Art Review

A description of the previous studies that discuss different issues faced by the sampling strategies for comparing organic and conventional farming will be presented. Then, a description of studies that focus on comparing the technical and environmental efficiencies between conventional and organic farming using stochastic frontiers and data envelopment analysis will be presented.

When focusing on comparing productivity and efficiency of different production systems, one main challenge arises is that how the sample is being constructed which if not properly designed will affect the estimated results and restrict the explanation of the results. To this end, the sampling strategy should consider different factors like farm structures between different farming systems; for example, in Europe, grassland and mixed farms dominate the organic agriculture, whereas, in conventional agriculture, the dominant is arable and meat producing farms [25]. Another factor is selection bias, which arises from the case that conventional farms may have changed to organic farms. A third factor is the representativeness and reliability difference between organic and conventional farms samples, since there is a small group of organic farms against a large group of conventional farms that might affect the quality of results. Offermann and Nieberg [37] have proposed a framework for comparing organic with conventional farms. To accommodate these issues, the literature has developed different strategies. A first strategy is using metafrontiers to make comparisons between organic and conventional farming [33]. For the sampling strategies, matching techniques are used to compare farming structures [34, 45] which helps to improve the data quality to make comparisons. Selectivity models are used to overcome the issue of potential selection bias arising from farms converting from conventional to organic [30].

In the following lines, a review on literature that compares technical efficiencies between conventional and organic farming using Data Envelopment Analysis (DEA). In this area, the literature has a large spectrum of studies (see, e.g., [2, 8, 9, 24, 34, 40, 43]). Poudel et al. [40] adopted the DEA model to compare the technical efficiencies between 120 conventional farms and 120 organic coffee farms in Nepal during the year 2011. Results show that the technical efficiency scores, on average, were 0.89 and 0.83 for organic and conventional coffee farming, respectively. Gutiérrez et al. [24] used a two-step DEA plus regression approach. In the first stage, a DEA model is used to assess 24 conventional and 26 organic farms for rain-fed cereals crops in Southern Spain. The results show that conventional production is less efficient than organic production and that the main cause of inefficiency for conventional production is excessive input consumption. While inorganic production, the source of inefficiency comes from output shortfalls. In the second stage, a fractional regression model was estimated to assess the impact of some exogenous variables on the obtained efficiency scores. The regression results confirm that organic production significantly decreases inefficiency.

In the following lines, a review on studies that compares the technical efficiencies between conventional and organic farming using Stochastic Frontier Model (SFA) (see, for example, [19, 22, 23, 28, 34, 36, 45]). Guesmi et al. [23] used SFA and a local maximum likelihood methodology following Kumbhakar et al. [32] to compare the technical efficiencies between 30 organic and 30 conventional farming in Egypt. Results show that the investigated farms operate with high mean efficiency scores; however, organic farmers, on average, have higher technical efficiency compared with their conventional counterparts (0.97 and 0.96, respectively).

A review paper elaborated by Lakner and Breustedt [33] provides a summary of studies that focus on technical efficiencies of organic farming and those that compare organic with conventional farming. The authors concluded that, based on the reviewed studies, first organic farming has lower productivity which can be attributed to production restrictions like the objective of producing environmentally friendly output; second, the efficiency of organic farming is found to be lower in the studies that take into account the sampling problems, while in the case of subsidies, results are mixed in terms of impact on technical efficiency ([Minviel and Latruffe 2013; 22]). Regarding the drivers of conversion from conventional to organic farming, the authors noted the literature is till young in this area and there is an ongoing debate on what these drivers which gives an opportunity to investigate in this area. Finally, the authors have indicated that the literature on environmental efficiencies is very important to develop proper policy measures. However, studies in this area are scarce due to substantial lack of data needed at the farm level that measure environmental indicators.

In the following lines, a review of the scares literature that compares environmental efficiencies between conventional and organic farming using DEA (see, e.g., [2, 24, 27, 43, 44]). Sutherland et al. [44] studied the performance of 16 organic and 16 conventional farms in England in two regions with high and low shares of organic farms. The authors have included two biodiversity indices besides the agricultural output. In regions with low shares of organic farming, conventional farms achieve higher efficiency. While in high organic shares region, organic farms outperform conventional farms. This is because the number of evaluated farms is very low; the DEA results should be tested for reliability as indicated by the authors.

Gultierrez et al. [24] used DEA to obtain joint economic-environmental scores for rain-fed cereal crops farm's in Southern Spain. The results showed that conventional producing farms are more efficient than organic farms, and the drivers of inefficiency for the conventional farms are excess use of inputs and greenhouse gases emissions. However, the sources of inefficiency for the organic farms are the gaps in production. Beltran-Esteve et al. [7] used a metafrontier model and DEA to investigate the managerial and technological differences in ecological efficiency of 200 organic and conventional citrus farms in Spain. The results suggest that moving from conventional to organic farming will contribute to reduce environmental impact by 80% without decreasing in economic performance. In terms of managerial capability, both systems show similar efficiency scores.

Based on the literature presented above, no study has been developed to compare the environmental efficiencies between organic and conventional farming using SFA. This work contributes to the efficiency literature by providing empirical evidence by means of SFA.

6.3 Industry Analysis

The production of H&S in Egypt is concentrated in middle governorates including Giza, Fayoum, Beni Suif, and Menia representing around 80% of the total production with a cultivated area more than 31 thousand feddans (1 feddan = 4200 m^2). As for farms sizes, it ranges from 5 to 200 feddans depending on the type of business whether it is family owned farm or private sector agribusiness with a total production of 176 thousand tons on 2003 (IMC [26]). Family owned farms are fragmented and represent the majority, while large-scale farmers and private sector agribusinesses are considered the H&S value chain leader who has access to the export market. This has forced exporters and processors not to deal directly with small-scale farmers, but rather deal with local traders who collect and grade the production from many farmers. Taking into consideration marketing channels are characterized by transport without refrigeration; hence, products have short shelf lives.

The organically cultivated area in Egypt has increased from 15 thousand hectares operated by 460 organic farms in 2006 to 85.1 thousand hectares operated by 790 producers in 2015 to 105,9 thousand hectares operated by 970 producers, 242 processors and 242 exporters in 2016 [17, 18]. The Egyptian Centre of Organic Agriculture (ECOA), one of the leading certification bodies in Egypt, has reported an increase of the registered organic cultivated area from 4020 to 9342 to 19,211 ha for the selected periods 1998, 2003, and 2008 [42]. The 105,1 thousand hectares of the Egyptian organically cultivated area in 2016 is distributed to 1.2 thousand hectares for citrus fruits production, 375 hectares for tropical and subtropical fruits, Grapes represent 1.9 thousand hectares, Oilseeds 1.6 thousand hectares, Olives 1 thousand hectares, vegetables 25.4 thousand hectares, cereals 8.2 thousand hectares, finally, cotton 581 ha that is operated by 584 farmers [18]. In 2016, for the agricultural land dedicated for organic production in Africa, Tanzania has the largest dedicated area for organic agriculture of 268.7 thousand hectares, Uganda represents 262.3 thousand hectares, Ethiopia represents 186.1 thousand hectares, and Tunisia represents 181.08 thousand hectares and Kenya with 154.5 thousand hectares, Egypt is 105,9. However, Egypt is considered the largest in Africa in terms of the organic share of the total agricultural land with a 2.8% as well as 20% share of organic operators are engaged in the organic processing in 2016 [18].

There is a well mature market for organic food in Egypt for its relevance as a farming system that ensures safe and high-quality food with positive environmentally friendly practices. However, till now there is no organic agriculture regulation in Egypt that can organize this market, yet Egypt is in the process of drafting a regulation, which is officially endorsed by IFOAM [18]. Additionally, the supply market is growing at a faster rate compared with consumption market [42]. This can be attributed to: first, consumers perceive organic food as a luxurious food; second, the focus of the supply is to the exportation, since 80% of production goes to exporting purposes that are dominated by 20% of the exporting companies and only 20% of the production is directed to the domestic market. Furthermore, almost 80% of H&S produced in Egypt from conventional practices and only 20% is from organic practices. This is because of the high cost and complexity of organic certification. Also, organic farms yield less production and require more elaborate skills which are not available in some parts of Egypt [41]. Moreover, the lack of support from the industry (i.e., training and technical support) for the farmers makes it harder for them to keep up with the updated quality standards.

This can be achieved by developing business-to-business schemes that improve the collaboration across the value chain. An example is the use of a contract farming as a tool to make sure the sustainable stable income for the farmers and ensures the quality of the H&S products to be delivered with specific qualities. The Egyptian ministry of agriculture has decreed a law for the creation of a center that manages contracts and through which it registers these contracts. The contracts are reviewed technically and legally upon registration by the center to make sure that the terms and conditions are fair for both parties. The registered contracts receive different services like using the registered contracts for finance; In the case of conflict, the parties can go for the center to settle the dispute and takes a technical decision that is final. The process of taking the decision depends on the type of agricultural product if it is perishable the time to take the decision is faster than non-perishable products.

The main challenge faced by H&S processors and exporters is the lack the research and development investments that lead to the limited benefit of creating high value-added H&S products. The most important H&S products produced in Egypt are fennel, marjoram, basil, peppermint, spearmint, and chamomile. A focus group survey was carried out by the IMC for the indicated products [26]. For coriander, the production is around 8000 tons with 7000 tons exported with 50% goes to Germany, 40% for Arab countries and 10 for Japan. For Egypt to maintain its exports, it requires to maintain its premium quality and focus on Egypt's main advantages, the ideal climate and the cheap labor. Egypt's main competitor is Morocco, which sells below Egypt's price to gain market share. For Marjoram, Egypt's exports all production, which is around 2000 tons. In terms of competition, Egypt is the leading in the international market. For chamomile, Egypt's production is around 6000 tons per year and achieves high yields with using hand picking. Egypt's estimated market share is around 60%, and the main competitors are Argentina and Eastern Europe. World demand is growing due to increasing health awareness. Despite handpick increases yield, demand for this type is decreasing because of the high cost, as a result mechanical harvesting is a need to because it is cost-effective. For basil, Egypt's production is 7000 tons and mostly for exports with Egypt is the leading exporter. With respect to fennel, production reached 8000 tons and largest importer is USA with around 4000 tons per year, with an edge in seed cleaning. Egypt is the biggest competitor to India with Egypt's market share is 65% and India is 35%. Peppermint and spearmint exports are around 1000 tons representing 75% of what is produced. Egypt edge is that China is the biggest producer of mwntholand supplies most of the world needs, and Egypt is a leading exporter. Egypt's major export market of H&S is expanding from EU to USA and neighboring countries in North Africa. Exports to the USA reached 3.5 thousand tons for the 2015/16, while Algeria receives 2.9 thousand tons. In Europe, Germany is the largest importer with 1.8 thousand tons [20].

According to the Egypt Herbs and Spices Market Research Report—Forecast to 2023 report in 2018 [15]. The spices market is the dominant market size reaching 82.8% compared with the herbs market. The main packaging material used plastic achieving 58.3% compared with paper and other materials. The dominant distribution channel is store-based with a concentration of 84.8%. The Egypt herbs and spices market reached a valuation of 94.8 million US dollars in 2017 and is expected to display a compound growth rate of 3.27% annually for the period 2018 and 2023. H&S are used in a variety of Egyptian cousin. They are used in different applications for traditional medicine apart from food flavoring and garnishing. Additionally, many of the H&S are used for personal care and cosmetics. The level of competition is not high since selected domestic brands control a sizable percentage of the market.

The key issues surveyed that face the H&S value chain stakeholders conducted by the IMC are: microbiological contamination, pesticides, poor processing practices, profit margins are getting squeezed, government regulations and lack of quality standards, lack of new products, government bodies, Lack of database, price wars and access to fund. In the following lines, these issues will be discussed in the following lines in more details.

- Microbial contamination is due to poor farming and hygiene practices since many of the workers are young children. Moreover, the problem of allowing the animals and chicken to move in the fields increases the potential of contamination. These practices can be avoided through training the farmers for good farming practices and risk management. Exporters deal with this issue by exporting the product for the nearest sterilizing facility and repack again for the European importers which cause cost to increase by 40% and time waste.
- The issue of pesticides where farmers are not aware of pesticides management in terms of use and suitable type for application. The government is taking measures for banning internationally rejected pesticides and developing pesticides guides to help increase farmers' awareness on the use control of the pesticide and market regulation through detecting unauthentic pesticides and establishing selling points that only sells authentic products.
- Poor processing practices is another key problem; specially, at the drying stage of the products that are done using different techniques, among which are the sun drying that may expose the plants to different contaminants, experienced farmers used special types of ovens.
- Squeezed profit margins achieved by the exporters due to the new import rules. More quality specifications are imposed that cause the cost to increase and to reduce the competitiveness of exporters.
- Prices fluctuations are influencing exporters as it changes significantly at a daily level.
- Local traders with low experiences interact with international clients and reduce prices just to have a deal and export low-quality products. Typically, importers rarely accept shipments from them, but importers use their quotations to negotiate with reputable exporters. They not only affect the price but also impact negatively

the image of Egyptian exports and create mistrust between importers and Egyptian products.

- Lack of quality control and standardization governing the domestic market and the exporters. The main requirement for exportation is to have a certificate providing information about pesticides levels and microbiological content of the pesticides residue laboratory from the ministry of agriculture. Additionally, the result of the laboratory is informative, and there is no regulation that bans the shipment from exportation if the contamination level is high. On the other side, due to lack of standardization, it is not clear how products grades are defined.
- Government regulations are restricting the importation of seeds, which does not help to improve the domestic varieties. Taking into account that importers are looking for quality products.
- Access to fund especially for small-scale farmers where production is most concentrated. Land fragmentation in Egypt is among the highest in the world; as a result, it does not allow for economies of scale.
- Lack of database as no producer, retailer, or exporters know their market share, the actual size of the market, and the level of competition.

The top issues that were widely reported within the focus groups are

1	No research and development	80%
2	Price wars	60%
3	Lack of database	100%
4	Contamination	50%

6.4 Methodology

Debreu [14] and Koopmans [29], first defined technical efficiency (TE). TE is based on the distance of the farm from the production frontier. Depending on the reference to measure efficiency, we have two different efficiency indicators that can be distinguished [31]. First, the output-oriented measure, referred to as a Debreu type of measure, is referred to as the ratio of the observed to maximum feasible output, assuming the production technology and the observed input use. Second, the input-oriented approach, referred to as Shephard-type measure, is defined as the ratio of the minimum possible to the actual input consumption, assuming a given level of technology and output. Both methods of measurements are the same under the condition of constant returns to scale [21]. The total economic efficiency of firms according to Farrell [16] is decomposed into two parts: the TE and the allocative efficiencies (AE). TE is the physical part, which reflects the capability of a firm to obtain the highest output from a given set of inputs, whereas the AE, the price component, reflects the capability of a firm to use the inputs in best proportions, assuming their prices and the technology level.

The assessment of farm TE and the factors that illustrates TE provides valuable information to enhance farm management and economic performance. Avoiding sources of inefficiency and waste of resources is necessary for economic sustainability. Generally, a farmer who operates with a high TE level obtains economic results better than a farmer who does not. In this regard, productive efficiency studies have important effects on economic performance, technological innovation, and the overall input use in the agricultural sector.

There are two leading approaches extensively used to estimate TE: parametric stochastic frontier analysis (SFA) or deterministic frontier analyses and nonparametric approaches like data envelopment analysis (DEA). Nonparametric techniques are more flexible than parametric approaches because they can be applied without knowing the proper specification of the functional form describing the production function. Bootstrapping techniques, which are nonparametric resampling methods, are used for statistical inference (Brümmer [10]). The DEA methodology distinguishes between input- and output-oriented models (Coelli et al. [13]) Furthermore, DEA technique allows for the calculation of metafrontier models that develops a frontier for a subgroup (e.g., organic vs. conventional farms) ([6, 9, 39]). However, they do not allow distinct inefficiency effects from random noise.

SFA was first introduced simultaneously by Aigner et al. [1] and Meeusen and Van den Broeck [35]; in their model, they differentiated between exogenous shocks outside the firm's control and inefficiency. In contrast to DEA and deterministic frontier analyses, SFA accounts for random noise and can be used to conduct conventional tests of hypotheses. The general model is specified as:

$$y_i = f(X_i; \beta)\exp(e_i);\ e_i = v_i - u_i, i = 1, 2, \ldots, N \tag{6.1}$$

where y_i represents the level of output and ith observation (farm); X is the vector of input quantities used by the ith farm in the production process; β is the vector of parameters to be estimated; and $f(X_i; \beta)$ is a suitable functional form for the frontier; we adopt the Cobb–Douglas functional form in the analysis. From a statistical point of view, the error term e_i in the model Eq. (6.1) can be decomposed into two components, u_i and v_i; it is assumed that u_i and v_i are independently distributed from each other. The different components of the stochastic frontier model are presented in (Fig. 6.1).

The first part v_i is a standard random variable capturing the random noise that arises from (a) the unintended omission of relevant variables from vector X_i [38]; (b) from measurement errors and approximation errors associated with the choice of the functional form; (c) unexpected changes in production (e.g., weather influences); and (d) other factors that are not under the control of the farm. The first part v_i is usually assumed to be symmetric, independent, and identically distributed as $N(0, \sigma^2)$. The random error v_i can be positive or negative, and so the stochastic output can vary about the deterministic part of the model (6.1). The second part, u_i, is a one-sided, nonnegative random variable representing the stochastic shortfall of the ith farm output from its production frontier, because of the existence of technical inefficiency. The definition of TE is based upon the distance of the firm from the pro-

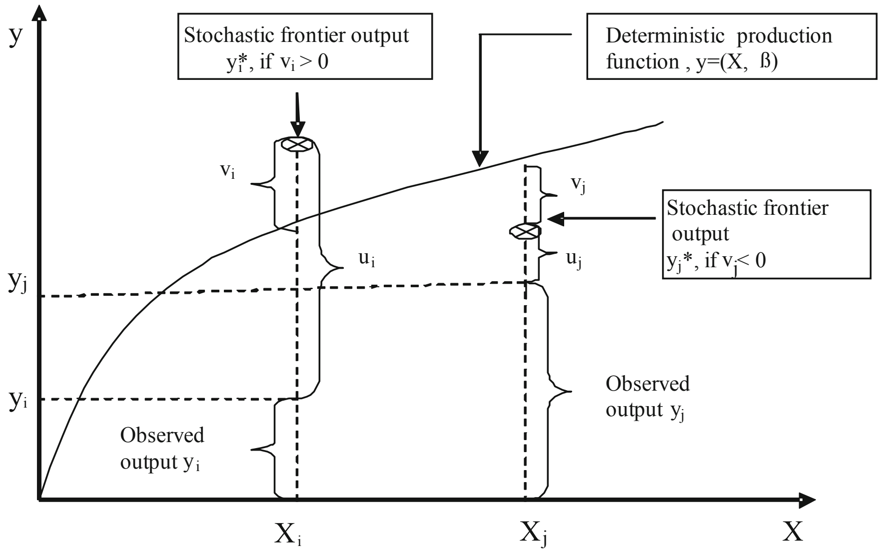

Fig. 6.1 Different components of the stochastic frontier (Battese [3])

duction frontier. Depending on the selection of the reference to measure efficiency, two different efficiency measures can be distinguished [31]. First, the input-oriented approach, referred to as Shephard-type measure, is defined as the ratio of the minimum feasible to observed input use, given the production technology and the level of output. Second, the output-oriented measure, referred to as a Debreu type of measure, is defined as the relation of the observed to maximum feasible output, given the inputs use and production technology. Both measures are identical under constant returns to scale [21]. In contrast to *vi*, several specifications of density distribution have been proposed for ui. The most common specifications are the half-normal, gamma, exponential, and truncated normal distributions. The truncated normal and gamma models allow for a wider range of distributional shapes. Battese and Coelli [4] suggested that the use of a single-stage approach yields more consistent and robust results than using the two-stage estimation procedure, which is inconsistent in its assumption regarding the independence of the inefficiency effects. These authors proposed the following TE effects model:

$$u_i = \delta_o + \sum_{m=1}^{M} \delta_m Z_{mi} + \varepsilon_i \tag{6.2}$$

where (Z_{mi}) are farm-specific variables associated with technical inefficiencies; δ_0 and δ_m are parameters to be estimated; and ε_i is a random variable with zero mean and finite variance $\left(\boldsymbol{\sigma}_{\varepsilon}^{2}\right)$ defined by the truncation of the normal distribution such that:

$$\varepsilon_i \geq -\left[\delta_o + \sum_{m=1}^{M} \delta_m Z_{mi}\right] \tag{6.3}$$

The mean of (u_i) is farm-specific, while the variance components are assumed to be equal $\left(\sigma_u^2 = \sigma_\varepsilon^2\right)$. The model formulation (6.2) recognizes and explains sources of inefficiency that change among farmers. The output-oriented measure of TE can be stated as the ratio of observed output to the corresponding stochastic frontier output; the measure takes a value between 0 and 1:

$$\text{TE}_i = \frac{y_i}{f(X_i;\beta)\exp(v_i)} = \frac{f(X_i;\beta)\exp(v_i)\exp(-u_i)}{f(X_i;\beta)\exp(v_i)} = \exp(-u_i) \tag{6.4}$$

Different procedures have been used in the literature to estimate the model presented above; the widely used procedures are maximum likelihood (ML) and corrected ordinary least square (COLS) techniques. Battese and Coelli [4] suggested the use of ML, showing that this estimator outperforms the COLS estimator in the case when the influence of the inefficiency error to the total error term is large. We estimate the parameters of the model defined by (6.1) and (6.2) by ML. The log likelihood function to be maximized for a sample of i producers is specified as:

$$\begin{aligned} \ln \text{L} = \text{constant} - \frac{1}{2}\ln\left(\sigma_u^2 + \sigma_v^2\right) - \sum_i \ln \Phi\left(\frac{u_i}{\sigma_u}\right) \\ + \sum_i \ln \Phi\left(\frac{u_i^*}{\sigma^*}\right) - \frac{1}{2}\sum_i \ln \frac{(\varepsilon_i + u_i)^2}{\sigma_u^2 + \sigma_v^2} \end{aligned} \tag{6.5}$$

As is usual, the variance parameters of the likelihood function are estimated in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$ following (Battese and Corra [5]); when γ is closer to one, deviations from the frontier are mainly due to the technical inefficiency effects. Conversely, when γ is close to zero, the deviations are mainly due to noise and the average response production function is an adequate representation of the data. On the other hand, one should note that γ cannot be interpreted as the ratio of the variance of the technical inefficiency term to the total residual variance. The variance of u_i is equal to $\gamma[(\pi - 2)/\pi]\sigma^2$ not σ_u^2. As a result, the relative contribution of inefficiency effects to the total variance γ^* is equal to $\gamma^* = \gamma/\left[\gamma + \frac{1-\gamma}{\pi/(\pi-2)}\right]$ following [12].

6.5 Results

Cross-sectional data is used in the analysis; data are collected from a sample via face-to-face interviews with farmers located in Fayoum, Beni Suif, and Menia governorates for winter 2016, specialized in the organic and conventional production of four types of herbs (Fennel, Marjoram, Spearmint, and Chamomile). The data collected represent farm and farmer's characteristics to be used in the assessment of technical efficiency for the conventional and organic farms. A sample of 232 farms was collected which consists of 135 organic farms and 97 conventional farms. The identification of the organic farms was based on a list of certified organic farmers obtained from ECOA.[1] The analysis was carried out using Stata 11 software. The Cobb–Douglas production function and the inefficiency models were estimated in one-step.

The variables included in the production function are as follows: the dependent variable (Yi) representing total production of herbs is measured in tons, and the factors of production are cultivated area ($X1$) measured in feddan (1 Hectare = 2.38 feddan), expenditure on fertilizers ($X2$), pesticides ($X3$), seeds ($X4$), labor ($X5$) and finally, machines ($X6$) are in measured in Egyptian pounds, while the variables of the inefficiency are equation ($Z1$) a dummy that reflects Beni Suif governorate, ($Z2$) a dummy that reflects Fayoum governorate, and ($Z3$) a dummy that reflects farmers' experience, i.e., the number of years dedicated to agriculture.

Descriptive statistics for the production structure of conventional and organic farms for the four crops are presented in (Table 6.1). Regarding the yield level, on average, organic farms are more productive than conventional, yet the increase is marginal. The average total cost per feddan for the three governorates shows that in the case of conventional farming Menia governorate has the lowest cost then Beni Suif and Fayoum. While in the case of organic farming, Beni Suif is the lowest as cost per feddan basis then Menia and Fayoum.

According to the results in (Table 6.2), the Cobb–Douglas production function estimates indicate that increasing the cultivated area, labor, and fertilizers in both organic and conventional farms will lead to the increase in herbs output with cultivated area and labor are being the largest contributor for organic farming. While crop protection inputs and seeds are found to have a negative impact, which is expected since an increase in pesticides, will have killed the plant beside the negative environmental impact, and seeds will increase the density of the plants in the unit area causing increased competition for nutrients and decrease production.

According to Table (6.3), farmers with more experience will be more technically efficient; that is, TE increases with the skills, and practice of farmer with experience has more effect on organic farms than conventional farms. However, the parameters are not found to be relevant, and this can be attributed to the long experience for both organic and conventional farms. The results also show that TE can be affected by the geographical location of farms. For organic farming, there is no statistical difference between the selected locations, which can be attributed to the homogeneity of adopting the rules of organic farming. However, for the conventional farming, Fayoum governorate was found to be more technically efficient compared with the other two locations.

[1] The Egyptian Center of Organic Agriculture (ECOA) is a domestic certification body for different types of organic farming certifications.

Table 6.1 Descriptive stats of farms' production and inputs

	Variable		Unit	Conventional farms average	Organic farms average
	Sample size			97	135
Fayoum	Yield	Fennel	Ton/fed	1.9	2
		Marjoram		2.5	2.7
		Spearmint		20	24
		Chamomile		0.87	1.1
		Area	fed	80	74
		Labor	L.E./fed	5982	6815
		Fertilizers	L.E/fed	2673	2393
		Pesticides	L.E/fed	487	506
		Machines	L.E/fed	1252	1433
		Seeds	L.E/fed	1206	1400
		Total cost		11600	12547
Beni Suif	Yield	Fennel	Ton/fed	0.9	1.2
		Marjoram		2	2.2
		Spearmint		16	18
		Chamomile		0.75	0.9
		Area	fed	89	86
		Labor	L.E./fed	5200	5940
		Fertilizers	LE/fed	1104	1212
		Pesticides	L.E/fed	592	561
		Machines	L.E/fed	1991	2194
		Seeds	L.E/fed	1900	1779
		Total cost		10787	11686
Menia	Yield	Fennel	Ton/fed	0.5	0.7
		Marjoram		0.9	1.2
		Spearmint		12	17
		Chamomile		0.7	0.8
		Area	fed	105	93
		Labor	L.E./fed	4586	6832
		Fertilizers	LE/fed	2314	2558
		Pesticides	L.E/fed	487	594
		Machines	L.E/fed	2210	2987
		Seeds	L.E/fed	1106	1552
		Total cost		10703	14523

Table 6.2 ML estimates for SPF parameters for conventional and organic data

Variables	Conventional farms estimate	Organic farms estimate
Cultivated area ($X1$)	0.236***(0.049)	0.932*** (0.000)
Fertilizers ($X2$)	0.250***(0.018)	0.132***(0.006)
Pesticides ($X3$)	−0.047(0.696)	−0.291***(0.005)
Seeds ($X4$)	−0.237***(0.016)	−0.110(0.273)
Labor ($X5$)	0.046(0.655)	0.419***(0.000)
Capital ($X6$)	0.179***(0.074)	−0.089(0.363)
Constant	−2.163***(0.029)	1.854***(0.000)
Sample size	100	135

*** indicate statistical significance at the 1%
P value in parenthesis

Table 6.3 ML estimates of the inefficiency effects model for both farms data

Variable	Conventional farms estimate	Organic farms estimate
Governorate1 (Beni Suif gov.) ($Z1$)	−0.102(0.436)	−0.704(0.470)
Governorate2 (Fayoum gov.) ($Z2$)	−0.424***(0.000)	−0.231(0.174)
Experience ($Z3$)	−0.006(0.190)	−0.005(0.382)
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.22	0.020
$\gamma = \sigma_u^2/\sigma^2$	0.105	0.507

***, (**), [*] indicate statistical significance at the 1%, (5%), [10%]
Standard error in parenthesis

According to Table 6.4, TE scores for conventional and organic farms are calculated as an output-oriented measure following Battese and Coelli [4]. The average technical efficiency score is 75% for conventional farms and 91% for organic farms. Moreover, these technical efficiencies range from a minimum of 56% for conventional farmers to 95% and a minimum of 75% to a maximum of 98% for organic farms. The results indicate that if organic farms effectively use available resources and at the current technology, it will be able to increase the output by 9% on average. Improving TE levels can reduce production costs and improve the economic viability of farms.

Improving efficiency may encompass upgrading farm operational activities, developing policies from the government and scientific research. At the research level, further analysis will help to identify other inefficiency causes, as well as their effect on efficiency with attention on those reasons that cause higher impacts on efficiency, and they should be the ones receiving further focus by farm managers and policy makers. Refined methods including risk attitudes may allow more accurate efficiency estimates.

Table 6.4 Frequency distribution of technical efficiency for farms

TE range (%)	Conventional	(%)	Organic	(%)
0–20	0	0	0	0
20–40	10	0	0	0
40–60	27	18	0	0
60–80	37	29	17	12.3
80–100	26	50	118	87.7
Total of sample	100	97	135	100
Mean efficiency	0.75	–	0.915	–
Minimum	0.562	–	0.749	–
Maximum	0.949	–	0.986	–

6.6 Conclusions

The objective of this study is to compare the efficiency scores of organic and conventional herbs and spices farms in Egypt and to attempt to identify the factors that affect technical efficiency levels. Productivity differences between the two agricultural practices are also measured using calculating the output elasticity of different inputs. To do so, we use the stochastic production frontier (SPF) methodology. Results derived from the SFA permit comparing output elasticity for different inputs between the two groups. The study shows that organic farms exhibit higher partial output elasticities for the cultivated area, labor, and livestock except for fertilizer and pesticides compared to conventional farms.

The results derive some interesting policy implications. Organic farms are more technically efficient than conventional farms since high technical efficiency is a prerequisite for economic efficiency [46]; this will provide incentives for more farms to adopt organic practices, which will lead to more production and access to the export market with price premiums, and additionally to promote organic production practices, strategies intended for information provision, extension services, education and training activities and providing financial assistance for farmers to adopt organic production.

6.7 Recommendations

The higher technical efficiency in organic farming obtained from the results can be attributed for different reasons. The costs per feddan supported by organic farming are found to be higher which will motivate the farmers to use their inputs more effectively as well as improving their performance. As suggested by Tzouvelekas et al. [46], making information available on how to apply organic farming practices can help to improve farmers' performance. Furthermore, high price premiums for organic products are another potential driver that explains the increase in technical efficiency.

Based on the results, there are a number of things that policy makers can do to improve efficiency in herbs and spices farming. First, experience is shown to reduce inefficiencies yet not significant due to lack of extension services that can increase the learning curve of the farmers and improve farming practices. Promoting capacity-building activities to farmers can lead to better production performance. Moreover, motivating the farmers to upgrade from family farming to commercial farms will help reducing technical inefficiency. On the other hand, motivating farmers to change to organic methods can help to increases in H&S farming efficiency. While conventional farmers indicate that higher price premiums of organic products are the motivation for their conversion, the organic farms obtain higher revenues per feddan, which allow covering for the high costs. Therefore, conventional sample farmers are not informed with respect to the performance of organic farmers. Information transfer through better extension services on the profitability of organic farms may help supporting the conversion to organic practices.

Changing market conditions like increased awareness of consumers and increased marketing power of intermediaries will lead to squeezed farm margins. For this reason, improving technical efficiency will increase the competitiveness of farmers that can help them tolerate times of markets hardships. Maximizing profit can be achieved either through higher price premiums or through reduced production costs. A cost reduction approach is especially pertinent in the organic farming sector, since consumers, in general, are reluctant to pay higher prices. Future research will not only focus on technical efficiency, which is the first component of economic efficiency, but also will investigate the allocative efficiency that represents the second component of economic efficiency and total factor productivity for each farming system. Since investigating only the tuning of the technical efficiency is not sufficient to be more competitive.

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Chapter 7
Biogas Production from Kitchen Wastes: Special Focus on Kitchen and Household Wastes in Egypt

Azza A. Mostafa, Bodor A. Elbanna, Fathy Elbehiry and Heba Elbasiouny

Abstract Pollutants are released into the atmosphere due to production and consumption energy especially from fossil. However, not only the environmental concerns but also the increase in energy demand promotes the researchers to develop new and current energy alternatives that cause zero- or low-negative environmental impact. Anaerobic fermentation can be used for the treatment of organic wastes (OW) such as kitchen waste, municipal solid waste, industrial organic waste, animal manure, and agricultural residues. The fuel produced from anaerobic digestion is environmental friendly. Kitchen wastes (KWs) are easily biodegradable organic material with high moisture, carbohydrate, lipid, and protein. The use of KW only in anaerobic digestion reduces the activity of methanogenic bacteria as a result of rapid accumulation of volatile fatty acids followed by a pH drop in the reactor, thus, adjusting C/N by some additives to accelerate the growth of methanogens and methane formation is necessary. The favorable pH for methanogens' growth range of 6.5 to 7.2. Furthermore, the key factors controlling the production of volatile fatty acids during fermentation for methanogenesis represented in pH, temperature, C/N ratio, and hydraulic retention time.

Keywords Kitchen wastes · Environmental problems · Biogas production · Anaerobic digestion

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7.1 Introduction

The common use of fossil fuels in the present energy infrastructure is the main source of anthropogenic emissions of carbon dioxide (CO_2), which is considered the largest reason for global warming and climate changing. Realizing solutions to the environmental problems that we meet today needs possible long-term solutions for sustainable development [10]. Increasing world energy demand and the incoming depletion of fossil fuels has increased concern in the development of renewable energy resources [17]. Renewable energy resources, such as solar, wind, geothermal, hydropower, and biofuels such as biogas, biodiesel, and bioethanol seem to be one of the most effective and effectual solutions. [10].

The amount of global waste production has increased in the past decade from 0.68 billion tons to 1.3 billion tons, and it is expected to be 2.2 billion tons by 2025. In addition to the increase in population, changes in lifestyle, industrialization, rapid economic growth, and grown rate of urbanization in lots of developing countries are some other reasons for the increased production of waste [11].

The treatment of organic wastes (OW) which includes industrial organic wastes, municipal solid wastes, animal manure, in addition to agricultural wastes by anaerobic digestion (AD) can be utilized as vehicle fuel or as co-generator of electricity and heat, and accordingly, can reduce greenhouse gas emissions (GHGs) [30].

Kitchen waste (KW), as organic waste, is an easily biodegradable organic matter with high-moisture, protein, carbohydrate, lipid contents. However, the major restraint of AD of KW alone is the rapid collection of volatile fatty acids then the pH drop in the reactor, which hinders methanogenic bacteria [7, 28]. To avoid such inhibition, using waste activated sludge to adjust C/N [5], and employing two-stage or three-stage systems [26] is very helpful.

7.2 Biogas Definition

Biogas, a mixture consisted mainly of methane (CH_4) and CO_2, is a renewable and cleaner type of energy that could partially offset the conventional petroleum-based energy sources. (i.e., oil, natural gas, and coal). Furthermore, it is not only alternative source energy but also an appropriate solution to environmental issues as well it is depleting faster [10, 32, 42]. Biogas production by the AD is gaining significant attention as an advanced sustainable energy technology [2]. Attention in biogas production has changed during the time from a source of energy production to a mean of waste management, nutrients delivery, and GHGs reduction and currently back to energy production through new perspective toward centralized plants [39]. Globally, much knowledge is currently available for the large-scale management of biogas production in controlled reactors. However, under conditions in developing countries, our knowledge is relatively low because of few studies of biogas production [33].

7.3 Advantages of Biogas Production

Globally, the consumption of renewable energy is growing. Concerns of energy security, efforts of mitigating the environmental impacts of conventional fuels, and improvements of the standards in living and renewable technologies are the components of sustainable energy usage. Therefore, bioenergy is known as a potential source, which can lead to a key role in indorsing renewable alternatives [44]. In the prospect of sustainable development, the role of biogas is becoming crucial. Indeed, recently, the worldwide bioenergy demand is greatly rising, and the anticipating indicates an additional rise to 2035, due to increasing the support strategies, by several governments over the world for reducing air pollution [29].

The usage of modern bioenergy has many benefits such as enhanced health and sanitation, creating job opportunities, replacing chemical fertilizers with organic fertilizer and reducing GHGs. Biogas production is a sustainable source of both energy and organic fertilizer (the bio-slurry) enriches the soil. As well, it provides a good opportunity to treat and re-utilize OW and reduces land-use problems related to the disposal of OW [38]. Furthermore, biogas production reduces GHGs emissions by substituting fossil fuels and diesel. It is usually produced from AD of several digestible organic substrates like domestic wastes and resources, or from landfills to produce renewable energy accompanied by reducing environmental risks from waste products in households, agriculture, and industry [9, 12, 16, 39, 46].

As well, the collection of biogas can be utilized for generating on-site thermal energy and electricity [9]. Chen et al. [8] reported that biogas is one of the most highly greatly opportunities to utilize particular types of biomass to satisfy some of the world's energy demands. Biogas refers to a mixture of gases generated by the biological degradation of OM in the absence of oxygen, where CH_4, H_2, and CO can be combusted or oxidized with oxygen. The energy output/input can record about 28.8 MJ/MJ under ideal conditions, providing very proficient usage of the valuable biomass. This resulting energy allows biogas using as a biofuel for replacing conventional fossil energy sources, such as coal, oil, natural gas, in power and heat production, as well as a versatile renewable energy source, especially to low-price fuel vehicles compared to diesel and petrol. As well, Matheri et al. [27] illustrated that in combustion, CH_4 is transferred into bioenergy not released to the surrounding environments.

Nevertheless, a small amount of CO_2 is released, but not affects the atmosphere compared to released CH_4 and nitrous oxide N_2O to the atmosphere. The presence of CH_4 and N_2O in the atmosphere has a great impact because of their greater ability to trap energy comparing to CO_2. Biogas also can contribute to a transition for a more circular and bio-based economy by supplying biomaterials and bioenergy [12]. Generally, widespread installation and appropriate functioning of biogas production systems can offer several advantages to users and the larger community. Of these advantages, energy sustainability, resource conservation, and environmental protection can be considered [8, 27].

Furthermore, the long-term utilization of reducing fossil fuels has reflected the unsustainability owing to their limited reservoirs and non-renewable nature. Subsequently, biogas derived from different biological sources can decline the heavy dependency on such depleting natural resources and give the attention to the energy insecurity concerns because of its renewable, broadly applicable, and plentiful characteristics. On the other hand, the valorization of the produced biogas is the energy efficiency (a typical electrical efficiency value is 33% while thermal efficiency value is 45%) and environmentally friendship due to the low emissions of hazardous pollutants, such as volatile organic compounds [8].

In brief, biogas is a gas produced through the AD and is primarily a mixture of CH_4 and CO_2 and smaller amounts of different substances. These substrates and types of production result in several compositions of the biogas. Finally, the raw biogas can be utilized as it is for generating electricity and heat, or purified into 97% methane and be used in the transporting sector [12]. However, recently, bioenergy and biogas production have faced increasing criticism, such as the effects on food prices and hence food security [13].

7.4 Appropriate Wastes for Biogas Production

Various low-cost materials such as sewage sludge, municipal wastes, food wastes, animal manure, and waste animal cadavers can be reacted for biogas production [16]. Ideally, biogas can be generated from the organic fraction of some material, such as crop residue, fruit waste, wood, industrial food waste, chicken feathers, textile wool, and lignocellulosic waste. Though, today, biogas is usually produced only from the easily utilizable feedstock by the microbial community responsible for converting this feedstock into biogas. Nevertheless, if this easily digestible feedstock (i.e., crop and livestock residues, wastewater with high-organic content, food waste, source sorted municipal waste, etc.) is not as plentiful or readily available for biogas production, the amount of produced biogas will be limited [31].

As mentioned before, biogas can be produced from KW, which is a simply biodegradable organic matter (OM) with high-moisture, protein, carbohydrate, lipid contents. The major limitation of AD of KW alone is the inhabitation of methanogenic bacteria due to rapid collection of volatile fatty acids after a pH drop in the reactor [7, 28]. Therefore, some material can be added to avoid this accumulation of volatile acid such as rice straw or animal manure [41]. Thus, the development of novel technologies that aim to utilize the readily available but not easily degradable feedstocks would develop the biogas production [31].

The major reasons for not perfecting some feedstocks for biogas production are representing in: (1) the inability or difficulty of digestion by microorganisms, (2) slow digestion, and (3) inhibitors present in the feedstock or producing inhibitory compounds through microbial degradation. For these reasons, the goal of the pretreatment (physical, chemical, physicochemical, and biological) is facilitating the digestion by eliminating these obstacles and making the organic content of the reacted material easily available and utilizable by the microbial communities [31].

7.5 Mechanism of Biogas Production

Biogas can be produced widely from solid or liquid wastes through the AD process. During the AD, several organic materials are degraded by microbial communities in anaerobic conditions, causing the production of energy-rich biogas used for many purposes such as vehicle fuel, electric power, or heat [10]. When the process is operated under the optimum conditions, the CH_4:CO_2 is around 60:40 [27]. Also, the plant nutrients in the digested organic material are reserved in a digestate, which can be applied as a plant fertilizer. In the AD, the rate-limiting time is hydrolysis. To improve hydrolysis and AD performance, pretreatment technique can be used as one possibility for that. Many pretreatment techniques can be applied (such as chemical, mechanical, thermal, or biological treatments). Many pretreatment techniques can be applied (such as chemical, mechanical, thermal, or biological treatments) to solubilize organic compounds and especially refractory compounds, and to make them more biodegradable. Furthermore, pretreatment can improve the OM reduction [10].

Biogas can be produced by AD using the locally presented residual biomass from different sources such as agricultural wastes, animal wastes, industrial wastewater, and domestic sewage). The AD of complex OM to biogas involves four main stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. A balanced process of CH_4 fermentation needs individual degradation phases to be achieved by distinct consortia of bacteria, namely fermentative bacteria, syntrophic acetogens, homoacetogens, hydrogenetrophic methanogens, and aceticlastic methanogens. The symbiotic relation among those microorganisms leads to efficient AD and biogas production. The final stage, conducted by CH_4 forming bacteria, is the most critical stage in biogas production because the methanogens transfer their primary substrates consisting of acetate, $H_{2,}$ and CO_2 into CH_4. There are two ways for CH_4 production, in which about 75% of CH_4 production arises from decarboxylation of acetate, and the other 25% come from CO_2 and H_2. As well, the CH_4 production stage is the most sensitive and rate-limiting stage in the whole process since CH_4-producing bacteria have a much slower growing speed compared to acid-producing bacteria and is sensitive to inhibitors like pH, temperature, ammonia, and other operative conditions. It is, therefore, necessary to maintain sufficient slow-growing methanogenic bacteria and protect active biomass from washing out from the fermenter and to decline inhibitory levels [8].

7.6 Biogas Digesters

Biogas is generated in an anaerobic digester operating in two way; mono-digestion or co-digestion. The last one favors high production of CH_4 due to the availability of several vital trace elements provided by different substrates, while in mono-digestion, these essential trace elements are lacking [27]. Biogas digesters realized as a green technology for utilizing animal manure into bioenergy and reducing environmental pollution. Therefore, millions of simple biogas unheated digesters are established underground in many developing countries [33].

The digesters design is varied based on geographic locations, substrate availability, and climatic conditions. For example, a digester used in mountains is designed to contain less gas volume to avoid gas loss. Whereas in the tropicals, it is preferred to contain digesters underground because of the geothermal energy. Out of all the various developed digesters, the fixed dome model in China and the floating drum model in India have continued to operate till today. Recently, the attention is increased toward plug flow digesters due to its portability and easy performance [34].

7.7 Kitchen Wastes (KWs) in Biogas Production

Due to the rapid growth of urban people and variations in consumption patterns, a large amount of KW is yearly generated. Thus, KW has globally become a major issue, if no reasonable treatment is adopted. The amount of these waste generates many challenges (in terms of protecting the environment and public health) and represents a huge amount of utilizable biomass [14, 23, 24]; Zhang et al. [48, 49]. Approximately, 1.3 billion tons of KW is generated yearly over the world. This amount of KW is growing continuously [36, 37]. Li and Jin [22] also affirmed that a great environmental challenge resulted from producing great amount of KW, and several harmful environmental effects may result due to ineffective treatment and disposal; such as odor pollution, water pollution, and garbage accumulation.

Disposal or ineffective of KW management such as disposing of open dumps causes several adverse consequences such as the public health hazards in addition to diseases (such as malaria, cholera, and typhoid). Thus, it not only causes polluting surface and groundwater because of leaching and further promoting the breeding of mosquitoes, flies, rats, and further disease-bearing vectors. It also emits an undesired odor and methane (which is the main greenhouse gas causing global warming). Also, the techniques such as incineration and pyrolysis have many disadvantages such as it is expensive and less effective for generating energy from KW because it contains high-moisture content [4]. Therefore, there is an urgent need for selecting eco-friendly options for saving the environment and natural resources. Reddy et al. [35]. Due to the environmental impacts of improper treatment of these wastes, its management has become an environmental and social concern [36, 37]. Moreover, with the upcoming global warming, ever-increasing energy costs, as well increasing cost in crop straw disposing of, more attention should be paid to the effective biomass disposal, such as bioconversion into methane-rich biogas [25]. Consequently, converting biodegradable KW into biogas has many benefits:

– Producing a renewable bioenergy from KW,
– Reducing air pollution,
– Finding eco-friendly methods for waste disposal,
– Generating revenue and wealth from the waste, and
– Reducing global warming [35].

For this purpose, the AD will be an economic and viable option [4]. The AD is a very promising technology for the effective management of OW such as KW [36, 37]. The high biodegradability of KW, in addition to its water content, makes it suitable for the AD with the associated advantage of biogas production. This is an appropriate solution for waste management because of its low cost, its low residual waste, and its usage as a renewable energy source. Furthermore, the resulting digestate can also be applied as a fertilizer or conditioner to the soil because it is nutrient-rich [23, 24]. Zhang et al. [48, 49] mentioned that AD, compared with any traditional landfill and burning, is a more attractive method for treating KW because it can produce biogas. In addition, the AD has a major advantage in reducing greenhouse gases emission since both methane and carbon dioxide produced in a closed reactor, which avoids its uncontrolled production and releases into the atmosphere.

7.8 Composition of Kitchen Wastes

The KW is comprised from organic rapidly biodegradable substances such as protein, carbohydrate, cellulose and lipids, and high-moisture content, which make it an attractive feedstock for operating an anaerobic digester [45]; Sahu et al. [18, 36, 37]. Wang et al. [43] confirmed that the high-organic compounds and moisture content of KW result in numerous harmful impacts such as water pollution, garbage accumulation, and odor pollution. Furthermore, high compositional variation in KW recorded in different parts of the world is a challenge to develop a robust technology for biogas production for the proper treatment and management of KW [36, 37]. Li et al. [23] added that KW has a high lipid content ranges from 2 to 3% (wet basis). This indicates that KW distinguished by a higher biochemical methane potential than other types of OW. Nevertheless, high lipid content has negative effects because of its low degradation rate, resulting in the increasing of intermediate products and weakens the stability and continuousness methane production. Li et al. [24] also reported that KW contents high amount of macromolecular organic matters in the KW (such as fat, oil, grease, and crude proteins) that estimated by 30–70% of the total content of dryly basis organic matter. This could easily result in rather longer started-up time when applying AD, as well, causing higher acidification and inhibi-

Table 7.1 Characterization of kitchen wastes [24]

Composition of KW		Characteristics of the KW	
Parameters	Percentage (%)	Parameters	KW
Cooked bone	2.7 ± 0.9	pH	6.5 ± 0.2
Cooked eggshell	1.0 ± 0.6	Total solids (%)	18.7 ± 0.4
Pasta and rice	29.1 ± 2.1	VS (%, dry basis)	93.2 ± 0.5
Fruit peeling	23.3 ± 1.2	Carbohydrate (%, wet basis)	11.8 ± 0.4
Cooked vegetables	19.5 ± 1.8	CP (%, wet basis)	2.5 ± 0.2
Vegetable peeling	23.0 ± 2.2	FOG (%, dry basis)	3.5 ± 0.1
Others	1.4 ± 0.2	Carbon (%, dry basis)	46.1 ± 1.7
		Hydrogen (%, dry basis)	6.9 ± 0.2
		Oxygen (%, dry basis)	37.8 ± 0.1
		Nitrogen (%, dry basis)	3.2 ± 0.3

tion of nutrients transport, thus the undesired condition for sustaining and stabling degradation during the digestion process. Wang et al. [43] also added at present, intensively research on the AD of KW has been performed since the OM in KW is suitable for anaerobic microbial growth. Thus, AD of KW could be not only highly effective for degradation of OM but also be able to supply renewable biomass energy and organic fertilizer. Although, the high-volatile solids of KW cause the fast hydrolysis during the digestion bringing about a severe acidification due to a drastic drop in pH followed by serious inhibiting to the methanogenesis. Li et al. [24] characterized KW as in Table 7.1.

Sahu et al. [36] explained (in Fig. 7.1) that complex carbohydrates (i.e., starch and cellulose) are degraded. During hydrolysis and acidogenesis into sugars that are consequently converted to fatty acids. On the other hand, fats are converted to glycerol and fatty acids, while proteins are converted to amino acids that are converted by deamination process into fatty acids and ammonia/amines. Fatty acids are exhausted by acetogens to generate acetic acid, which is used by methanogens for methane production. The rapid breakdown of KW results in high-volatile fatty acids and ammonia production. The accumulation of both compounds affects adversely the process of the biomethanation process. Thus, as mention by [1], AD is a highly sophisticated process that includes four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. However, they mentioned that many reports revealed the advantages of separating the breaking down the process into two stages optimized each either for acidification or methane production. In the first one, biopolymers are broken down into monomers such as various volatile short-chain fatty acids, while in the second stage, generated acids are converted into CH_4 and CO_2.

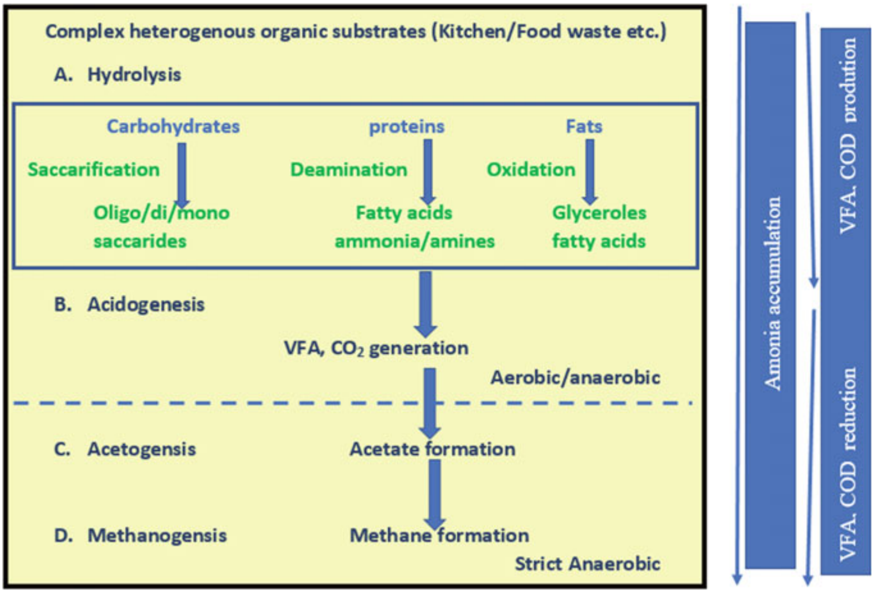

Fig. 7.1 Overview of biogas production from kitchen wastes [36]

7.9 Anaerobic Digestion for Biogas Production

The AD is the process of breaking down OM of wastes for producing biogas and biofertilizer, resulting in efficient resource recovery along with conserving non-renewable energy resources [36, 37]. Ye et al. [45] also reported that AD has become a recognized and established technology for the treating the organic wastes such as agricultural residues, animal manure, municipal solid waste, and industrial organic waste. Producing a vehicle fuel or co-generating of electricity and heat is the main benefit of this process, and thus reducing the greenhouse gas emissions.

Therefore, the AD, as one of the most credible commercial solutions for biogas production [47] and one of the biological treatments for organic wastes (OW), is getting growing attention because of its high valorization value for waste. AD of OW provides good opportunities for energy regeneration and nutrient reclamation which needless requirement of space and input energy for operating than composting, landfilling, and incineration [6]. However, the AD is a complex process for bioenergy production since the included biochemical and physical mechanisms are not yet obviously understood, which make bioreactor design, set-up and control not yet fully optimized [21]. Sahu et al. [36, 37] stated that KW is contained of organic substances such as protein, carbohydrate, cellulose, and fats (which are rapidly biodegraded and making it an attractive feedstock for running the AD). However, the AD plants meet difficulties in getting clean feedstock which leads to technical problems. Furthermore, there were found significant compositional variations in KW worldwide, posing a challenge to the developing production technology.

Furthermore, the AD is a very sensitive process including diverse microorganisms with ultimate functioning environmental conditions. As well, the type and structure of substrates influence the efficacy of biogas production. However, the AD is a suitable and effective technology for managing organic materials, as well it is expected to play a vital role in the forthcoming renewable energy production [15]. As well, Patinvoh et al. [31] emphasized also on that biogas production through AD technology has advanced greatly over time. Currently, due to high energy demand and environmental concerns because of increasing the world's population, the drive for AD anaerobic digestion technology is receiving momentum within research and the industry for generating sustainable energy resources. They also added, although the previous advantages of the AD, many challenges such as high retention time, the existence of some toxic compounds (that can inhibit the process), low biogas product, and high investment cost obstruct the highest performance of biogas production in AD systems. These bottlenecks are highly reliant on the availability, composition, and degradability of the digested material for biogas production. However, the abundance of such low-cost materials (i.e., organic wastes) confirm that there is an urgent need for finding new approaches for better utilization of these wastes [31].

The organic reacted materials are mainly consisting of proteins, carbohydrates, and lipids which can be broken down into simple composites by microorganisms in an oxygen-free (anaerobic) environment with the subsequent process stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [15]. As AD is a multistage microbial process, production rate and proficiency largely depend on some factors such as substrate temperature, pH level, hydraulic retention time (HRT), and substrate solid content. Temperature, as one of the most effective factors, controls the microbial growth rate and its activities inside the digester. Recently, mesophilic temperature regime (25–40 °C) is operated in most digesters for many reasons such as lower energy requirements and higher stability than thermophilic treatment (>45 °C) [47].

The microbial communities in an AD reactor contain three typical populations (i.e., fermentative bacteria, acetogenic bacteria, and methanogenic bacteria). Methanogenic bacteria is the most sensitive to environmental changes due to their slower growth than fermentative and acetogenic bacteria [25].

Energy conversion efficacy is the most critical issue for energy production. Both the AD biogas production and biogas upgrading depend on chemical scrubbing needs additional thermal energy in their stages. In an ideal AD biogas plant, about 10–15% of the generated energy is internally utilized for heating substrates. While, in other chemical scrubbing processes such as the amine-based process, the thermal production of CO_2 rich solvent, for releasing captured CO_2, uses a large amount of heat and concurrently with producing a large amount of waste heat that is generally not allowed in the cooling system [46].

7.10 Affecting Factors on Biogas Production

Biogas production is affected by the added amount of organic materials, the digester pH, toxic substances, and anaerobic condition C:N ratio. Additionally, biogas production is influenced by the characteristics and chemical composition of the primary organic materials which lead to significant effects on the efficiency of decomposition of the anaerobic organic materials and methane production. The ratio in the components of organic wastes varies based on seasons and regions, and the performance of the AD differs accordingly [19]. Stefaniuk et al. [40] reported that in the fermentation process, the use materials are in various proportions as well at various temperatures (i.e., mesophilic, thermophilic). Abendroth et al. [1] stated that high temperature from 200 to 300 is required for increasing the accessibility of lignocellulose. However, they also reported recent studies to suggest that low temperatures (such as 120 °C) or even 70 °C can already considerably increase degradability. Stable reactor functioning has been stated even for hyperthermophilic digestion circumstances up to at least 65 °C, however, at such temperatures, microorganisms require very long adaptation periods.

In addition, Wang et al. [43] reported that during the AD, volatile fatty acid determines pH which considers one of the most important factors affecting AD. The serious, volatile fatty acid inhibition on the methanogens activity results from a pH drop in reactors, which may cause the activity loss of acid-sensitive glycolytic enzymes. As well, high levels of undissociated acids will damage macromolecules. The fermentative bacteria pH ranges from 4.0 to 8.5 (they are not sensitive to changes in pH values), while a limiting range of 6.5–7.2 is desired for methanogens' growth. Improving volatile fatty acid content and its suitable component are required for methanogenesis. Therefore, pH, temperature, C:N ratio and hydraulic retention period had been stated to be the essential factors controlling volatile fatty acid production during fermentation. Stable pH conditions around neutral were required for protecting the methanogens and its growth.

7.11 Pretreatment for Enhancing Anaerobic Digestion for Kitchen Wastes

Pretreatment is a key step to improve the substrate characteristics to increase the AD. For this target, several pretreatment options, such as microwave, ultrasonic, chemical thermal, electrical, and freeze/thaw techniques, can be performed. The effects of such pretreatments are highly different based on the characterization of the substrate and the pretreatment type [23]. Li et al. [24] added that previous researches have largely focused on optimizing the AD conditions of KW, (either single, double or three stages, continuous/sequencing-batch digestion, retention time and temperature and of digestion, mono- or co-digestion, etc.). As well they focused on the factors affecting inhibiting of the digestion process feedstock (i.e., C/N ratio, ammonia nitrogen, organic compositions, salt content, volatile fatty acid, long-chain fatty acid, organic loads, etc.). In addition, they paid attention to the pretreatment methods (e.g., biological, thermal, chemical and thermochemical, ultrasonic and microwave pretreatment) for enhancing organic reduction and methane production. Furthermore, the long retention period of the AD of KW is a major issue and several methods have been developed for pretreating KW before the AD process for accelerating the digestion process and enhancing the biomethane production [24]. Of the pretreatments, a thermal method is one of the most studied pretreatments and has been successfully used at the industrial scale. This pretreatment leads to the solubilization of organic compounds, reducing the exogenous pollution, and disinfection by sterilization, this favors the hydrolysis step, increases the production biogas, and reduces the retention period. Furthermore, it also enhances phase separation, which enhances the recovery rate of floating oil, which can be applied as the raw oil for producing biodiesel. In addition, its removal effectively alleviates the induced biological inhibitory reactions [23]. Abendroth et al. [1] mentioned that thermal pretreatment, that need high energy (temperatures as high as 200–300 °C), can successfully elevate the accessibility of lignocellulose.

As well, Zhao and Ruan [50] stated that KW is not very effective and stable because of accumulating the volatile fatty acids. Thus, co-digestion of KW with organic wastes, such as agricultural straw, municipal sludge, and animal manure become more popular. Zhao and Ruan [50] also mentioned that co-digestion of Taihu algae and KW could balance the nutrients fermentation during the digestion process. Ye et al. [45] also states that great efforts have been spent to avoid volatile compounds accumulation to ensure the efficiency of AD of KW; such as co-digestion with dairy manure, applying waste activated sludge for adjusting C/N, using trace metals to accelerate the methanogens growth and methane formation and utilizing two- or three-stage systems. Zhang et al. [48] stated that recently, KW had become a critical problem because of its environmental pollution. Afterward, the AD process, the resultant digested effluent from KW can still severely pollute the environment due to its high pollutants' concentration, mainly ammonium and phosphate. However, this effluent can be utilized in something such as applying to microalgae cultivation, which can not only reduce the pollutants' concentration but also can effectively utilize the nutrients for biodiesel production. Additionally, cultivating microalgae in this effluent would also reduce the cultivation cost.

The KW contains easily convertible carbohydrates, (such as starchy compounds), and highly recalcitrant components (such as lignocelluloses. Lignocellulosic materials which mainly consist of carbohydrates (including cellulose and hemicellulose), lignin, and extraneous materials. Therefore, pretreatment process is very necessary for efficient bioconversion of these components. In this context, using diluted sulfuric acid is one of the most efficient pretreatments (Fig. 7.2) which widely applied in this purpose [18].

Recently, few studies have examined the co-digestion of black water (i.e., urine and faecal matter) and KW in the anaerobic system. As well, to avoid the issues raised over accumulation of ammonia, the addition of brown water (i.e., faecal matter without urine) to KW before the AD was also studied. Brown water can improve

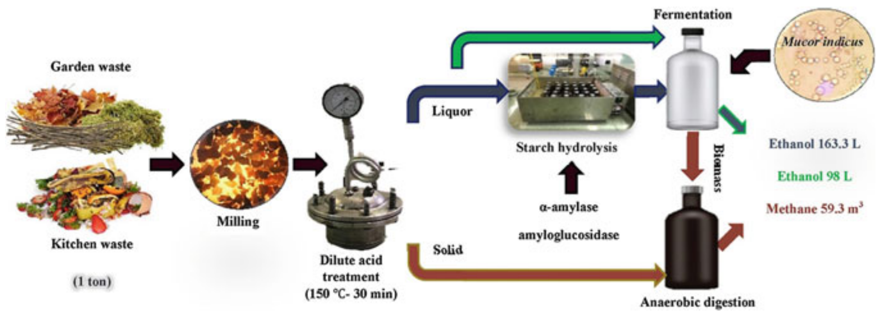

Fig. 7.2 Biogas and ethanol production from kitchen wastes after pretreatment by diluted acid [18]

the stability of the AD process by maintaining the buffer capacity and providing additional nutrients. The advantages of co-digesting brown water and KW were elevating biogas production in addition to the remarkable biodegradation efficiencies after adding brown water as a co-substrate to the anaerobic breakdown of KW. This is likely because of the adequate buffering capacity provided by brown water to KW digestion. Subsequently, methane production by anaerobic co-digestion of KW and brown water not only provides a greener and cheaper alternative to disposal, but may also help to reduce the using of fossil-fuel-derived energy and, thus, the negative impacts on global warming [20].

7.12 Digestate and Plant Nutrition

Digestate is the residual product of the AD process and contains a lot of essential nutrients for plant growth. Thus, it can be applied as biofertilizer [12]. Such fertilizer is rich in nutrients and organic matter. It also integrates the characteristics of slow and quick acting fertilizers. These fertilizers are distinguished by consuming low net energy compared to chemical fertilizers, and consequently, this biofertilizer produces more CO_2 to the atmosphere [38]. Stefaniuk et al. [40] also state that there is another product of anaerobic fermentation apart from biogas, this product fermentation is the post-fermentation digestate (RBP), this digestate is often separated into two phases (i.e., liquid and solid). RBP can be composted, or landfilled, but it is mostly used as an agricultural fertilizer. Nevertheless, the studies show some disadvantages of the direct application of RBP to soils which makes it limited to soil application. These disadvantages are represented in the probability to contain some harmful things such as heavy metals, seeds of weeds or infrequent parasites and polycyclic aromatic hydrocarbons in addition to the high mobility of its nutrients which causes leaching of the nutrients from the soils to groundwater and increases the eutrophication of water.

7.13 Proposed Roadmap for Egypt

In Egypt either in rural or urban areas, tons of KW are produced yearly. According to the ministry of environment in Egypt, there are thousands of tons from collected yearly from garbage (Table 7.2). These wastes present a challenge in terms of eliminating and disposing of them. However, as mentioned above, these wastes are a potential source of wealth. Thus, each household (or group of households) can benefit from this potential source in generating biogas, especially with raising the energy costs. Installing biogas units will be more effective and mostly more beneficial in case of utilizing the kitchen wastes from group of households as well animal manure for more AD efficiency. According to Amigun and von Blottnitz [3], there are several small/medium biogas digesters (>100 m^3) in Egypt and few large ones ($\leq$100m^3) with a high technology level.

In a primary experiment for unpublished work for the authors of this chapter, kitchen wastes 6 kg of kitchen wastes +1.5 kg cow manure +30 L water was mixed in a large plastic tank connected by tire frame (as a storage for produced biogas) such as presented in Fig. 7.3. This means that the percentage of KW to animal manure was 4:1. After 20 days, remarkable amount of gas was noticed (the tire frame became swollen). This is affirmed the above-mentioned statement that animal manure is working as an activator for the anaerobic digestion of KW to improve biogas production in addition to utilizing digestate as a fertilizer. Therefore, it is very important to enhance the methods of biogas production from KW, especially these wastes equal to approximately 30% of all household wastes yearly.

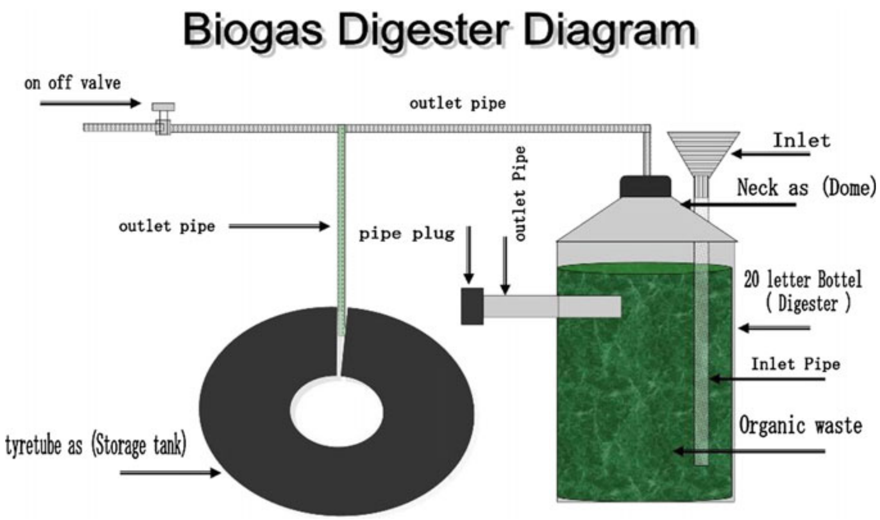

Fig. 7.3 Biogas digester diagram (WWW.PAKSC.ORG)

Table 7.2 Garbage weight and quantity by authority which get rid of it by governorate 2017 (http://www.sis.gov.eg)

Governorate	Authority which get rid of garbage		
	[a]Garbage collectors (Ton)	Garbage gathering companies (Ton)	City council district (Ton)
Cairo	1065	264	2331
Alexandria	55	714	2051
Port-Said	453	43	284
Suez	–	–	30
Damietta	–	20	691
Dakahlia	6	124	685
Sharkia	1	31	782
Kalyobia	163	484	870
Kafr El-Sheikh	1	14	141
Gharbia	98	49	516
Menoufia	–	9	423
Behera	2	12	308
Ismailia	4	106	370
Giza	282	199	587
Beni-Suef	1	1	101
Fayoum	103	–	1730
Menia	–	9	262
Asyout	15	–	158
Suhag	40	–	191
Qena	–	1	117
Aswan	–	25	41
Luxor	–	3	22
Red Sea	–	244	–
ElWadi ElGidid	–	–	83
Matrouh	–	–	96
North Sinai			40
South Sinai	8	2	20
Total	2297	2354	12,932

[a]Garbage collection from house

7.14 Conclusions

Kitchen wastes are increased day by day because of increasing world population. This will pose many impacts on the environment in case of an appropriate disposing burning, or wasting potential resources. Biogas production from kitchen wastes will solve many of such environmental problems, especially with elevating the energy price in all over the world. Anaerobic digestion after some pretreatments will be very effective method in utilizing these easy digestible wastes and generation biogas. It is supposed that this method will help many households either rural or urban ones not only to benefit from KW as a potential source of wealth and saving many in purchasing energy, but also to contribute in solving environmental problems from accumulating wastes. Thus, this method is promising in biogas production.

7.15 Recommendations

The authors highlight the following recommendations:

1. Investigating new methods and pretreatments to minimize the problems of utilize kitchen wastes in biogas production for households and improve the biogas generation from such valuable wastes, and
2. Supporting the decision makers and governments to the households for installing biogas units with low cost.

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Chapter 8
Agricultural Waste Management for Climate Change Mitigation: Some Implications to Egypt

Heba Elbasiouny, Bodor A. Elbanna, Esraa Al-Najoli, Amal Alsherief, Shimaa Negm, Esraa Abou El-Nour, Aya Nofal and Sara Sharabash

Abstract Human activity is increasing the concentration of atmospheric greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). As a result, pollution and a significant warming of the earth's surface are happening and thus expected climate changes and its adverse impacts on the environment. Due to increasing population growth during the few last decades, agriculture wastes were increasingly generated day by day. Most of these wastes are misused either by burning or disposing with unsuitable methods. This not only consumes potential valuable resources but also increases the GHGs emission in the earth's atmosphere. Therefore, utilizing and managing these wastes with eco-friendly and sustainable manner will lead to mitigate the emission of GHGs and climate change impacts. There are traditional and modern methods for utilizing agricultural wastes for these purposes. These methods utilize agricultural wastes in animal feeding, composting, bioenergy resources, bioplastic and building material base. Therefore, exploring new and alternative methods for utilizing these potentially valuable resources and changing people behavior toward this is very necessary.

Keywords Agriculture waste · Climate change · Mitigation · Greenhouse emissions · Environment

8.1 Introduction

Human activity is increasing the concentration of atmospheric greenhouse gases (GHGs). As a result, significant warming of the earth's surface is expected in addition to other associated climate changes within the next few decades. The GHGs are causing the largest contribution to global warming including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). All three gases are produced through the

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management and disposal of wastes [1]. Therefore, environmental pollutions and energy saving are among the greatest challenges facing the humankind in the current century [2].

Waste generation is rising day by day due to the population growth which directly influences the environment and economy [3]. Recently, agricultural wastes have become a significant source of pollution. The random burning of wastes such as straw and livestock dung in the agricultural country has led to series of environmental problems [4]. The increasing quantity of waste and its inappropriate removal especially in developing countries have always been pressing the safety of environment's population health, and alongside, amplifying the contributing of these countries in the global GHGs emission [5].

As indicated by the research, all agricultural wastes have incredible potential benefits. Thus, the effective transformation of these wastes, recycling and utilization, is very significant in the control of environmental pollution [4] and GHGs emission. Therefore, finding ways to adapt to climate change and its countless potential impacts is one of the greatest challenges of climate change [6]. Therefore, utilizing all the resources in the agricultural sector is needed to maximize the yields of agricultural production. However, intensifying the usage of production elements for vertical and horizontal expansion is resulting in an increase of the annual amount of agricultural wastes which accumulate without suitable managing. Therefore, there is an urgent need for activating the most suitable methods for transforming such agricultural wastes into economic and valuable materials. These materials can add increasing value to agricultural crops and productivity, energy saving, enhancing the environmental quality, and increasing the rates of self-sufficiency [7]. He et al. [8] also affirmed that agricultural wastes have great ecological service and economic value, and this could not only relieve the ecological, environmental pollution but also would decline the agricultural production demand for limited resources. Attitudes must, consequently, be changed from believing crop residues as undesired wastes to considering them as an integral part of agricultural production [9].

8.2 Agricultural Waste Definition

Agricultural wastes are defined by many researchers as follows: "the outcome of agricultural production following the different harvesting activities" Abou Hussein and Sawan [9], as well, Sarnklong et al. [10] referred to the crop's straw as the residues after agricultural crop harvest and emphasizes that it is the main by-product of agriculture production. It also defined as "any substance or object which the holder discards or intends or is required to discard" [9, 11] **and** also referred residues as wastes and reported that is depending on whether they have or do not have a use. They also mentioned that residues are often referred to as "co-products." Zaman and Lehmann [12] referred the solid waste as "any trash, garbage, refuse or abandoned materials which have 'no economic value' or functions for anybody." As well, Zaman and Lehmann [13] pointed to wastes generally as "the symbols of the inefficiency of any modern society and a representation of misallocated resources." Singh et al. [14] stated that "the word 'Waste' normally emphasis something around us which should be recycled, reused, reduced or even eliminated, if possible."

8.3 Obstacles of Utilizing of Agricultural Waste

There are many obstacles facing the utilization of agricultural wastes, for example, rice straw, as low-cost biomass, is difficult to be collected because of high costs and logistical costs since "most of the rice straw is produced by smallholder farmers." Wheat straw is collected and used for many purposes in many countries. However, the cost for wheat straw depends largely on local circumstances. In some regions, a lot of straw is collected for certain purposes like animal bedding. In others, wheat straw is not utilized [15]. Wang et al. [4] mentioned that there were problems facing the utilization processes of agricultural wastes such as the large quantity and unknown amount of these wastes. The utilizing and disposing problems focus on the agricultural wastes include backwardness of techniques, gaps of agricultural automation, deferred policies, and social service systems [4].

8.4 Agricultural Waste Sources

- **Crop residue (agricultural wastes)**: wastes that resulted after harvesting rice straw, corn leaves, cobs, cassava stem, cane trash, peanut shell, coconut shell, leaves, etc. Rice, corn, wheat/barley, cotton, and sugarcane are the five crops with the highest amount of waste.
- **Agro-industrial residues**: that is, wastes that are resulted from processing on rice husks biogases, peanut shells, cassava peels, coffee husks.
- **Hazardous wastes**: such as excess pesticides and fertilizers, and
- **Animal wastes**: [9, 16].

8.5 Agricultural Waste Composition

Agricultural residues consist mainly of cellulose and lignin, which jointly represents 85–90% of the dry matter content; the remaining 15–10% includes simple sugars, starch, fat, wax, ash, essential oils, gums, tannins, pectin, and among other substances. Most of cellulose materials in such residues are known as "holocellulose" which includes three fractions of cellulose (i.e., α-cellulose, ß-cellulose, and γ-cellulose); the combination of ß-cellulose and γ-cellulose is known as hemicellulose [17]. Elfeki and Tkadlec [18] added that these wastes are characterized as coarse plant by-products and "big size, chemically low in protein and fat contents."

8.6 Wastes and Climate Change

Recently, agricultural wastes have considered an important pollution source [4]. Climate change is considered as a major global challenge that has motivated the international community to apply mitigation strategies aiming at limiting the average rising of global temperature [19]. Biomass burning has a significant impact on the chemistry of global atmosphere because it provides large source of CO_2, N_2O, and hydrocarbons [20]. In this context, Viana et al. [21] also explained that globally, biomass burning represents an important source of atmospheric GHGs and aerosols, with a great interannual variability. However, biomass burning emissions cause positive and negative effects on the climate. For example, smoke and aerosol particles have a cooling effect in the atmosphere because they directly scatter sunlight or reflect it to space. However, black carbon particles have a warming effect because of absorption of incoming radiation. Smoke particles are a main source of cloud condensation nucleus. Clouds, which contain a higher number of smaller droplets, reflect more solar radiation into space, and as the clouds are less likely to produce rain, cloud coverage may also increase. However, smoke emissions do not only have a cooling effect on the atmosphere but a warming one as well. Some of the gases emitted by biomass burning, such as CO_2 and CH_4, are GHGs and thus share in the greenhouse effect that heats the atmosphere through absorbing thermal radiation. Further than these direct influences, indirect and semi-direct influences of biomass burning emissions have also been detected. Aerosols modify the microphysical and thus consequently the radiative characteristics and amount of clouds (i.e., the large number of cloud condensation nucleus). This will lead to increase in cloud coverage or to decrease it because of the increase in temperature due to the absorption of incoming radiation by elemental carbon particles [21].

Recently, many of agriculture wastes have been produced yearly around the world. Agricultural wastes annually increased at an average of 5–10%. The unreasonable utilization would cause many problems such as soil and air, for example, the burning of straw and manure will generate a lot of smoke and dust, harmful gases, seriously leading to air pollution. As well, animal manure contains many parasite eggs, pathogens, heavy metals, and so on. Furthermore, A part of these agricultural residues has been directly discharged into the water bodies, causing serious contamination of the aquatic environment [4]. In addition, Song et al. [22] added also confirmed that food and agricultural systems heavily rely on fossil fuel energy. Petroleum is almost used in every stage of food production, from fertilizers production to mechanized planting, irrigation, harvesting, cooling, and transportation. Furthermore, discarding food in a landfill makes it decompose anaerobically and yield CH_4 emissions.

People generate approximately 150 billion metric tons of agricultural biomass wastes yearly. These wastes can use as a major source of energy or raw materials [23]. The occurrence of agricultural wastes differs from place to place. For instance, in Egypt, 97% of its area is a desert, and less than 4% of the land is suitable for agriculture. The agricultural activities result in economic part of the crop (i.e., the yield) and less important part (i.e., agricultural waste). With the introducing of technology in the agricultural process, wastes have become a burden due to the occasioned destruction and environmental pollution. In addition, statistics point out that agricultural wastes reach about 30 million tons nationally. The type and quantity of agricultural wastes in Egypt change from village to other and from year to other because of the farmers always desire to cultivate the most profitable crops that suited to both of land and environment [9].

The increased generation of crop straw residues has a wide range of adverse effects on human health, energy, and environment safety [24]. Most of the developing countries are seeking practical solutions, either legal or illegal. However, it was shown from the literature that the selection of the waste treatment technologies is based on their cost-effectiveness and contributions for meeting some locally, regionally, or nationally imposed purposes, while the criterion of mitigating climate change has not been considered. For example, in a region of Malaysia, the optimal scenario for managing municipal solid waste would be able to accomplish the renewable energy target and, recycling target and boost composting as an alternative for waste reduction [5]. As well, Yevich and Logan [20] reported that there are two important components of biomass burning: (1) the incineration of agricultural waste, wood and charcoal as household fuel, and (2) the combustion of crop wastes in open fields. They also confirmed that as the populations of developing countries continue to rise, the contributions of these biomass burnings increase. They also added that a quantitative description of the spatial distribution of such burning is needed to assess the impact of this burning on the budgets of trace gases.

Using of rice straw may offset carbon, N_2O, and fine dust emissions from field burning as a public disposal method for rice and wheat straws. As well, it retains the minerals in the ash. Legislation to forbid field burning results in disposal problems in many countries. Compared to other types of straw (e.g., wheat straw, corn stover), rice straw management can be distinguished by its most common disposal technique: open field burning. Field burning of straw is often the most cost-effective technique for rice farmers to quickly dispose of straw. While some nutrients (e.g., potassium) are largely contained in the field, a lot of C and N are released and not going to field. Although there are no official information, estimates indicate that farmers burnt about 80% of rice straw in certain regions. Moreover, there are also differences in straw burning methods (e.g., pile burning, or straw burning that is evenly spread over the field) [15].

Hasty actions and unsound decisions of the future use of residues for bioenergy production and GHGs emission reduction might have considerable negative socioeconomic and environmental impacts. However, primary crop residues have many significant ecosystem functions and provide a potential wealth of ecosystem services to humankind as well to the environment. This go far beyond the provision of bioenergy and C storage for the reducing GHGs emission. Regulating services are provided when agricultural wastes are kept on the soil, contributing to agricultural productivity, to adaptation to climate change variability and mitigation. More specifically, their services present in minimizing the soil erosion, reducing the evaporation of soil water, helping to increase the infiltration of rainwater and capture the precipitation from snow, delivering essential nutrients, and constituting an important basis for soil C, a media for soil life, a habitat for micro- and macroorganisms, and a tool for weed management. Therefore, the protection of soil resources entails savings of external inputs such as fertilizers and soil amendments, concurrently lowering the requirements of external energy consumption [25].

Furthermore, inappropriate manure storage in large-scale and traditional animal production rises GHGs emission because waste is often combined in large lagoons and holding ponds instead of being directly incorporated into soil. Gaseous products (such as CO_2, H_2S, NH_3, and CH_4) are produced and released into the atmosphere through manure storage and decomposition. Research has demonstrated that manure stored on conventional farms emitted approximately 25% more CH_4 gas than organic farms, indicating the significant impact of organic animal production on reducing GHGs emission [6].

8.7 Waste Management for Climate Change Mitigation

Waste management means the collection, transport, recovery, and disposal of waste, involving the supervision of such processes and the after-care of disposal sites [11].

As population growth increases, changes in lifestyle and consumption patterns increase and have been the main motivations of an increased waste production which causes various impacts on environment and public health. In the last decades, waste management became a main issue, and several processes have been innovated for organic wastes treatment such as composting. Nevertheless, some wastes cannot be composted (e.g., oils) because of its low economic cost in addition to waste reduction in landfills [26]. Waste management system was changed long before the development of our recent civilization. Various key innovations have been occurred historically in waste management development. In this context, four major key innovations can be considered in waste management systems, with different main technologies, methods, and tools [12, 27]. Zaman and Lehmann [12] illustrated the schematic waves of these innovations in waste management systems in Fig. 8.1 as follows: (1) open dumping which is still available in various low-income countries; (2) uncontrolled landfill; (3) waste composting; and (4) the recycling and controlled landfill. In the twentieth century, waste-to-energy technologies become the fifth wave of waste management systems, while in the twenty-first century, the zero waste becomes the sixth wave in waste management systems and the most holistic innovation for waste management systems for reaching a true sense of sustainability in the waste management systems.

Pietzsch et al. [28] referred to zero waste as "a broader approach when compared to that described in the solid waste hierarchy," They also point that zero waste is "a term refers to a unifying the concept that embraces a series of measures that aim to eliminate waste and to challenge traditional thoughts," Also, they reported that waste is a resource under zero waste concept. Singh et al. [14] categorized the zero waste into subsystems; (1) zero waste in administration and manufacture; (2) zero resource waste (3) zero emissions; (4) zero waste in product life and; (5) zero toxic use.

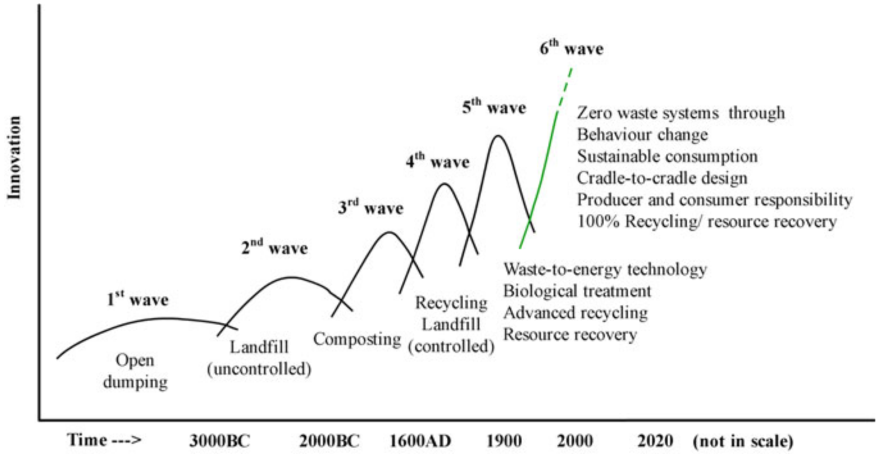

Fig. 8.1 Innovation waves in waste management systems. *Source* Zaman and Lehmann [12]

It is worth mention that circular economy as a sustainable economic growth mode considers the highly effective use of the resources as well the circulation uses as a core, considers 3Rs (i.e., reduce, reuse, and recycle) as the principle, and considers low consumption, low emissions, high efficiency as characteristics. Each of 3Rs has three aspects as following:

– Reduce: (1) reducing material, water, and energy input; (2) reducing product manufacturing that originally not needed, and (3) reducing the people's demand not the quality of life.
– Reuse: (1) considering a thing multipurpose; (2) developing with waste as raw material remanufacturing industry, and (3) using the renewable resources substitution non-renewable resources as much as possible.
– Recycle: (1) consider the wastes of raw materials to become the initiative interior materials circulation; (2) building technology park; and (3) constructing circular economic system differ that from traditional, recognize resource recycling utilization [29].

Xuan et al. [29] also illustrated that in the agricultural development of the circular economy, the greatest difference with traditional agriculture is the resource conservation and recycling. This considers the way of modern agricultural production technology of a revolution (see Fig. 8.2).

The waste management hierarchy is accepted guide for prioritizing waste management systems nationally and internationally to achieve optimal resource utilization and environmental outcomes. It orders the waste management practices, ascendingly from most to least preferred to: waste prevention; reusing; recycling; composting, incineration, and final landfill. Therefore, this hierarchy is one of the guiding principles of the zero waste system [22]. Loiseau et al. [30] reported that the waste hierarchy approach, in addition to, and the wastes prevention are important elements

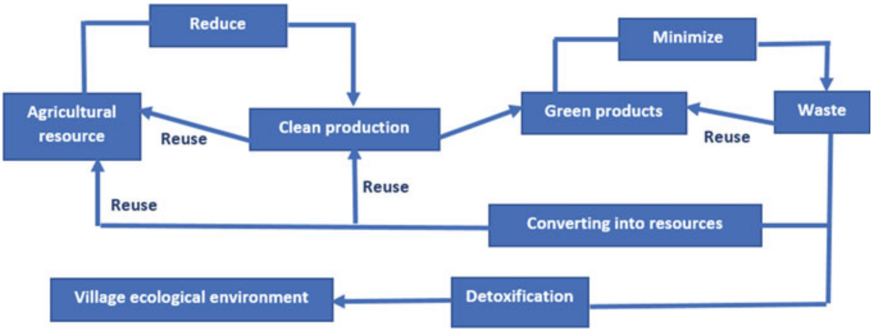

Fig. 8.2 Agricultural resource recycling [29]

of green economy by improving resource efficiency, reducing need for raw materials, and aiming at closing the material flows. Lausselet et al. [19] also emphasized on that waste management is based on the waste hierarchy, which sets the following priority order: prevention, reuse, recycling, energy recovery, and disposal, as the least favored option. Furthermore, protecting the environment and the public is the purpose of waste management by keeping manure and contaminated waters far from surface and groundwater and governing the application of manure nutrients to crops, hence such that nutrients are available in the right quantity, at the perfecting time and the suitable place [31]. Adeniran et al. [32] reported that an integrated waste management system is one of the main challenges facing sustainable development. Many factors have aggravated the problem of utilizing agricultural wastes including [7, 9]:

(1) the absence of environmental awareness;
(2) low knowledge level and skills influencing the behavior of farmers in handling agricultural waste;
(3) burning agricultural wastes such as happened in the rice-cultivated fields which generates many poisonous and harmful oxides and hydrocarbonates;
(4) many farmers now consider the residue utilization as an additional cost with small returns; and
(5) furthermore, they consider the best way to get rid of those residues by dumping, open burning, etc., but the environmental hazards of such practices cannot be ignored. Thus, the misuse of these wastes represents dangerous environmental damage and a dissipation of an important economic resource.

Global climate change is the most environmental challenge society facing. Atmospheric CO_2, CH_4, and N_2O are the most effective long-lived GHGs that contribute to global warming. Agriculture contributes to approximately 10–12% of total global anthropogenic GHGs emission and is realized as an important source of GHGs emission. CO_2 and CH_4 emissions are derived in cropland from different practices such as biomass burning, soil tillage, drainage, rice management, flooding, the application of fertilizers as well residues. N_2O is derived in the agricultural sector from the activities of soil microorganisms, such as nitrification and denitrification processes, that can be declined by the field management practices such as no-tillage and straw return. Although the livestock sector contributes about 40–50% of agricultural GDP, it also should be responsible for GHGs emission of 5.6–7.5 Gt CO_2-eq/yr; therefore, to mitigate global warming potential, it is so important to reduce the emissions from manures or wastes and to motivate carbon sequestration [33]. Asim et al. [23] reported that local agricultural wastes are associated with two significant issues: decomposing of agricultural wastes emits CH_4 and leachate. Furthermore, farmers usually burn local agricultural wastes producing not only CO_2, but also other local pollutants. Therefore, proper management of agricultural wastes can decline water and soil contamination, mitigate climate change, reduce local air pollution, and reduce environmental depletion.

Therefore, agricultural wastes management goals are representing in:

(1) Maximizing the economic benefit from the waste resource: It is necessary to focus on increasing the value of these wastes to maximize farmers' profit and the overall return of the agricultural production.
(2) Maintaining acceptable environmental standards: If wastes are not properly handled, they can pollute surface and groundwater and contribute to air pollution. Therefore, proper waste management reduces the expected environmental risks on farmers and reducing the hazardous of environment pollution and the waste of its various elements [7, 34].
    Hence, an integrated waste management approach is one of the major challenges facing sustainable development [32].

Then, agricultural residues must certainly be disposed or utilized for specific purposes to avoid many problems such as contamination, pest growth, occupying large areas of land and hampering agricultural work [17]. Agricultural wastes should be recognized as a resource that might be utilized for many purposes such as animal feed, compost, or biogas without negative impact on the environment [18]. As the above-mentioned reasons and explanations, it is important to learn and train farmers how to maximize their benefits from agricultural wastes, by recycling economically valuable materials, to generate further income which could help raise their income and living standard [7]. Effective waste management is one of the big challenges in most Arab countries, such as Egypt, due to increasing population growth rate as well, rapid urbanization. As an accompanying feature, implementation of such management systems is normally hampered by lack of many crucial ingredients, such as information, organization, financial resources, complexity, or system multidimensionality. According to published data and information from local sources, there is no ultimate or common rate for all Arab countries at which wastes are generated. This is because differs from country to another and among different regions within the same country, according to community characteristics, social conditions, and average income in each area. Although many research studies have been performed to determine effective factors influencing waste management systems in cities of developing countries, only a few gave quantitative information. In 2008, the Arab Forum for Environment and Development stated that statistics and data about quantities of solid waste in most Arab countries are not available. Regarding solid municipal waste, the gross generated quantity from Arab countries is estimated at 81.3 million ton yearly based on an average rate of about 0.7 kg per capita daily [18].

8.8 Traditional Uses of Agricultural Wastes

Farmers usually are using crop residues very well for many purposes such as building, heating, livestock feeding, and fertilizing. Agriculture modernization and economic and social development are enough reasons leading to deep changes in rural energy and the structure of feedstuffs; as a result, the traditional approaches for applications of crop residues have declined and plans of modern approaches for utilizing these residues have expanded. Hence, waste should be handled as a by-product to combine the old traditions and modern technologies for sustainable development achievement [9].

Traditionally, there are many new attractive and profitable approaches for utilizing crop residues. **Crop residue can be used for providing an** organic source to the soil, animal feed and padding, mushroom production, cooking, utensil making, compost production, and energy production. Furthermore, several research programs are proceeding in the USA, several European countries, China, India, and other countries to use biomass. However, the attention is paid to the five crops with the highest amount of wastes (i.e., rice, corn, wheat/barley, cotton, and sugarcane) [9, 16].

(1) **Animal Feeding**: Despite the abundance of agricultural wastes, there are many places in the world suffering from a lack of animal feed materials such as Egypt, and consequently import a large proportion of these materials annually to fill the gap of feeding and the deficit in the feed budget that tends to rise yearly. Hence, there is an urgent need to motivate the attention to recycle the crop wastes for animal feeding [7].

– **Treatment with Urea and Injection with Ammonia**

In most developing countries, the limited availability of protein source is a problem for animal feeding although great efforts have been done to find alternative supplements. On the other hand, crop residues have a high fiber content and are low in protein, starch, and fat. Cell walls of straw primarily are lignin, cellulose, and hemicelluloses. Therefore, the traditional method to increase livestock production by supplementing forage and pasture with grains and proteins concentrate may not meet future meat protein needs. Transforming wastes into animal foodstuffs would help in a greater deal in overcoming the deficiency of animal foodstuffs. This is because these wastes have a high content of fiber while low protein, starch, and fat make them not easily digestible and the size of the waste in its natural form might be too big or tough for the animals to eat. To overcome these problems, several methods were used to transform the agricultural waste into a more edible form with higher nutritional value and better digestibility. The chemical treatment method with urea or ammonia is more feasible than the mechanical treatment method [9]. On the other hand, rice straw is high in lignin and silica [9, 35]. Both those components play an important role in reducing the digestibility of straw. The crude protein content of rice straw is generally between 3 and 5% of the dry matter. Any crop residue with less than 8% crude protein is considered inadequate as a livestock feed because it is unlikely that such residues, without supplementation, could sustain nitrogen balance in the animal. Rice straw is the most abundant feed resource for ruminant animals in Vietnam especially during the dry season [9].

– **Silage Production**

Major percent of the forages such as wheat, maize, grasses, and legumes are produced and stored as silage. The process is maintaining the wet forage crops under anaerobic condition to improve its nutrient content. Thus, pH will decline, and the wet forage is conserved from spoilage microorganisms. This technique is safe, easy to use, and does not pollute the environment. Therefore, the products are considered as natural products [36].

(2) **Composting**: Although composting is a methodology boosts recycling of organic wastes, it is approved by the UNFCCC as one of the few methodologies that reduce emission related to agriculture [37]. It is worth notice here that there are different types of compost: Green compost is made from tree and yard wastes, crop residues, and other wastes of plant origin; and brown compost which obtained from animal manure, municipal organic wastes, and kitchen and canteen wastes [38]. By composting, organic matter generated from multiple waste methods is going through a process which kills pathogens. It results in stable organic material used in agricultural soils as a soil conditioner which improves soil fertility, structure, water holding capacity, and buffering capacity. Composting is only acknowledged as a project for emission reduction if only the "baseline scenario" in a certain country causes significant GHG emissions. This is, for instance, the status in Egypt, where most wastes are landfilled or illegally dumped. In this case, some processes such as fermentation or rotting will start because of a lack of oxygen. Through fermentation, microbes will emit CH_4, a GHG which is about 25 times greater than CO_2. The new composting scenario avoids the CH_4 emission of for a substantial part. However, it causes more emissions as a result of biomass transport and fuel use on the composting facility. As well, the emissions of N_2O because of microbial activities may be higher through composting than through fermentation [37]. Andersen et al. [39] added that the main potential disadvantage of composting is generation and emission of gaseous compounds such as CH_4, N_2O, and carbon monoxide (CO). The emission of CO_2 from composting activities is derived from plant material breakdown and is usually considered as neutral in terms of affecting global warming (i.e., the global warming potential (GWP) of CO_2 is zero). In the contrary, CH_4 and N_2O are strong GHGs and are recognized as contributors to the greenhouse effect. This is because the GWP is 25 and 298 for CH_4

and N_2O, respectively, indicating that they are higher 25 and 298 times potent GHGs than CO_2 over a century time horizon. Budgeting of GHGs' emission from composting activities is important toward the development of technologies for alleviating emissions and improving the accuracy of considerations for quantifiable compost emission models. This should improve consistency, comparability, and accuracy of emissions' data reported via various national and international databases.

Smith et al. [1] reported the potential of compost to replace the use of mineral fertilizers. Compost consists of significant concentrations of the three macronutrients for the plant; NPK: nitrogen phosphorus and potassium. Although their concentrations in compost are low in comparison with inorganic fertilizers, they may nevertheless be of value to crops and reduce the need for inorganic fertilizer applications. In the case of N, the plant nutrient required in greatest quantities, nearly all the N present in compost is incorporated into organic compounds. This N only becomes available for uptake by plants after microorganisms have converted the organic N into inorganic forms, namely ammonium (NH^{4+}) and nitrate (NO^{3-}) ions. Inorganic fertilizers provide a source of N to the crop that is therefore readily available at the time required by the growth of the crop. However, there are several potential adverse impacts of inorganic fertilizer use. **Groundwater pollution**: Inorganic N supplied in excess of the crop's immediate needs may be leached out of the soil by infiltrating water, threatening contamination of groundwater resources. **N_2O release**: Denitrifying bacteria convert NO^{3-} to N_2O at anaerobic microsites in the soil, thus contributing to the greenhouse effect. Emissions from fertilizer production: Production of fertilizers is very energy-intensive, causing CO_2 release from fossil fuels, and production of N fertilizers also causes the release of N_2O.

(3) **Food Production**

– **Mushroom Production**

Application of rice straw for plantation of mushrooms is well known. Recently, oyster mushrooms (*Pleurotus* spp.) have become increasingly common and are now cultivated in several subtropical and temperate countries ([9]). It grows rapidly on many agrowastes such as wheat straw, olive cake, banana leaves, tomato tuff, and pine needles [40]. Its commercial cultivation is mostly done on straw, but in some places such as Singapore, the non-composted cotton waste accompanied with rice bran and calcium carbonate is used and also proved an effectual substrate. Rice straw is an essential substrate for the growing of *Agaricus bisporus* in Asia, whereas in Japan, Taiwan, and Korea, rice straw composts have been used with consistent results for many years. Rice straw has enough nutrients and considered the best suitable material for mushroom growing in all producing countries such as China, the Philippines, and Indonesia. Cotton wastes can also be used for mushroom production ([9]).

(4) **Renewable Energy Resources**

The world's present economy is highly dependent on several fossil energy sources like oil, coal, and natural gas. These are being used to produce fuel, electricity, and other goods. Excessive consumption of such fuel resources, especially in large urban areas, has led to the generation of high pollution levels during the last few decades. The level of GHGs in the earth's atmosphere has drastically raised. As well, with the increasing human population rate and increasing industrial prosperity, energy consumption also has increased globally. As the annual global oil production begins to decline in the future, there is a need to rapidly reduce the emission of GHGs, increase the renewable energy production, and improve the resource efficiency [41, 42]. Subsequently, alternative renewable energy sources such as wind, water, sun, biomass, and geothermal heat should be considered for the energy industry. All petroleum-based fuel sources can be replaced by renewable biomass sources like bioethanol, biodiesel, biohydrogen, etc., which can be derived from many sources such as sugarcane, corn, and switchgrass algae [42].

In the last decade, the growing interest in bioenergy production and the promotion of sustainable agriculture have resulted in the need for enhancing crop residue management. Crop wastes are historically applied for other purposes, such as bedding and feed for livestock, a substrate for mushroom production as well as raw material for cooking [25].

With upcoming global warming, excessive increasing energy costs, and elevated cost of crop wastes disposal, more concern should be directed to the efficient disposal methods of biomass, such as its bioconversion into methane-rich biogas [24]. Tora et al. [43] reported that if the agricultural wastes can be an energy source, the embedded energy should be extracted efficiently. To do that, different technologies can be used such as:

(1) Combustion processes can release the heat content of the agricultural wastes;
(2) Fermentation as a biological method that can convert the embedded energy content into fuels;
(3) Biodiesel production as a chemical conversion method to convert the biomass into diesel; and
(4) Pyrolysis and gasification as thermochemical conversion methods to release the heat content and in turn to produce high-heating valuable oil and gaseous mixtures.

As reported by Tora et al. [43], gasification is an effective technology that can convert the agricultural residues into gaseous mixture. However, it is a complicated process taking place in different stages. "The process is endothermic at the beginning, and then becomes exothermic in the remaining of the process". Sarkar et al. [42] stated that biogas has also been identified as a possible motor fuel on organic farms in the rapid and intermediate terms. Biogas is made by anaerobic digestion of organic materials. When used as biofuel, CO_2 is separated from the gas for increasing the content and the gaseous fuel can be kept at high pressure. Matheri et al. [44] and Dahiya et al. [45] stated that biogas is comprised of gases such as CH_4,

CO_2, H_2, CO, hydrogen sulfide (H_2S), ammonia NH3, and a trace amount of oxygen (O_2). It is produced under controlled conditions by the bacterial decomposition of biodegradable organic materials. These materials include municipal solid waste and agricultural, industrial and animal wastes. When operating the process at optimum conditions, the ratio of CH_4:CO_2 is about 60:40. Biogas is a source of bioenergy, and when it is produced with satisfactory amount and standard, it can be utilized for electricity or heating. In addition, in combustion, CH_4 is converted into bioenergy. Thus, it is not released to the surroundings. Nevertheless, CO_2 is released in a small amount that does not affect the atmosphere compared to that of CH_4 and N_2O when they are in the atmosphere (because in this case they have a great impact as a result of their greater ability to trap energy comparing to CO_2).

In general, biogas energy techniques have lower GHGs emission than fossil energy ones, especially when biogas is used as fuel in transportation [46, 19]. Also emphasized that biogas is clean renewable energy generated anaerobically and can substitute traditional sources of energy such as fossil fuels, and oil. Pérez-Camacho and Curry [41] stated the most common utilization option for the biogas is its combustion in a biogas engine to produce electricity and/or heat. However, the biogas can also be promoted for other utilization options such as biomethane or biodiesel as part of a larger bioenergy system, or utilized for energy and chemicals production in the biorefinery concept.

Recently, ethanol is the most widely consumed liquid biofuel for motor vehicles. The importance of ethanol is rising due to several reasons such as global warming and climate change. Bioethanol has been receiving widespread interest internationally, nationally, and regionally. The global market for bioethanol has entered a stage of rapid, transitional growth. Many countries worldwide are shifting their attention to renewable sources of power production as well as transport fuel because of depleting the crude oil reserves. Therefore, ethanol has potential as a valuable [42]. Asim et al. [23] mentioned some energy products from converted agricultural wastes such as ethanol, biodiesel, methanol, heat and steam, oil, synthetic fuel, producer gas, and charcoal.

Li et al. [47] reported that although a huge quantity of wastes still unutilized, progressively more concern is being paid to ecological issues and then, more waste is being reused and recycled. Some of the researches focused on using wastes as fertilizers, others concerned using these wastes for biogas production. However, a comparison of the GHGs emission of agricultural wastes used for fertilizers and those wastes used for biogas productions looks to be lacking [47].

8.9 Modern Uses of Agricultural Wastes

Nowadays, there are many uses and utilizations of agricultural wastes of these:

Bioplastic Production from Agricultural Wastes

Population growth has led to increasing the growth in agricultural activities, thus increasing the generation of agricultural wastes indirectly. The petroleum-based traditional seedling and plantation plant pots or polybags are considered the most widely wastes generated. These pots and polybags are non-biodegradable and usually are disposed after usage in landfills which will lead to pollution. To solve this issue, the concerned industries are investigating to find an alternative for these non-biodegradable pots and bags. Because the level of environmental awareness elevated, the public starts recycling wastes with the help of new technology [48]. Emadian et al. [49] stated that worldwide, 34 million tons of plastic wastes are generated yearly, and 93% of these wastes are disposed in landfills or oceans. Some members of the European Union (EU) have forbidden landfilling applications. However, about 50% of these wastes are still disposed in landfills. Although many countries such as Sweden, Germany, Netherlands, Denmark, and Austria succeed to achieve 80–100% in the recovery of plastic wastes, the recycling was only 28% on average. Although the EU countries attempt to combat the disposing of plastic wastes and develop reusing and recycling applications, developing countries are still relying on conventional landfilling. The plastic consumption in developing countries has been reported to be more than that of the world average because of the higher rate of urbanization and economic development. The recycled newspaper pulp fibers are used as a basic source for biofiber materials for many purposes such as construction, paperboard packaging, newsprint, insulation, or building materials. To maximize the using of recycled newspaper pulp fiber, industries are searching for more usage of such fibers into other products. Bioplastic pot is one of these products; it is a mixture of newspaper pulp fibers and bioplastic. It will be an alternative for other type (i.e., non-degradable plantation and seedling plant pot). As well, the presence of newspaper pulp fibers and bioplastic can produce high durable and degradable pots. Additionally, swelling of pots, caused by water absorption during production and planting process, can be reduced by occurrence of bioplastic in these pots [48].

Emadian et al. [49] also reported that plastic is the most commonly used polymer in our daily life, especially in packaging usages. The annual production of this petroleum-based plastic was higher than 300 million ton in 2015. This excessive production of this kind of plastics requires sustainable alternatives from renewable resources. Additionally, the negative environmental impacts such as CO_2 emissions and their long accumulation in the environment as a result to their non-biodegradability are the significant problems of using this non-biodegradable plastic.

Concrete Production from Agricultural Wastes

Nowadays, concrete has become the widest building material used in the construction industry. Besides its strength, it can easily be molded into any form, as well, it is an engineered material meet most desired specification. Also, it is also adaptable, easily obtained incombustible, and affordable. Today, it is extensively used. However, unfortunately, a great quantity of concrete is being produced. The effect of which is contrary to its advantages, the concrete industry has had a huge effect on the environment. As well, the CO_2 emission is resulted during its industrial process with a large raw material content to produce billions of tons of concrete globally every year. The cement industry only is responsible for approximately 7% of all the CO_2 generated globally. Also, the demolition waste of concrete and its environmental impact has made the concrete industry is no-friendly and unsuitable for sustainable development. Thus, many studies attempted to focus on discovering alternatives to cement, for instance, agricultural and industrial wastes that are disposable and less valuable, with potential benefits can through reusing, recycling, and renewing programs. Previous studies revealed that some agrowastes could be used as an alternative for cement in cement-based materials. This can provide materials more environmentally friendly in such industries [50]. Rice husk ash, fly ash, bagasse, coconut ash, etc., are the main agrowastes source of cement or concrete production. The use of such material in the building material industries has gained growing interest because of various environmental, economic, technical, and specialized product quality reason [51].

In addition to previous products of agricultural wastes, there are other usages. It can used as a raw material for many products such as textiles, panel boards, cordage, paper product insulators, and upholstery. The other examples are presented in the production of activated carbon from hulls after the biodiesel processing and polymeric composites from the seed cake [23].

8.10 Agricultural Wastes: Some Implications to Egypt

In Egypt, the consumption of petroleum products and natural gas as traditional source for energy increased year by year as shown in Table 8.1. Subsequently, CO_2 emissions and the cost of environmental impacts on the national economy increased yearly. Nile Delta, Egypt, is one of the most vulnerable areas to the potential impacts and climate change risks [52]. Therefore, utilizing agricultural wastes to generate clean and renewable energy resource is required in the future to overcome the previously mentioned environmental problems from misusing of agricultural wastes.

In 2012, agricultural wastes in Egypt were estimated as 30 million ton (about 82,200 ton daily). A huge portion of these wastes was either burned in the fields or wrongly dumped on the banks and drains. This creates obstacles to water flow and water quality. Burning of agricultural crop wastes (especially crop wastes) present a problem in Egypt. Rice cultivation in Egypt is estimated by approximately 360,000 ha of rice based on 2008 statistics, with a rice straw production of 6 million ton [53]. Data in Table 8.2 present pollutants that have reduced as a result of processing with rice straw (2010–2013) as an action to minimize the pollutants resulted from rice straw burning.

Table 8.1 Quantity and cost of CO_2 emissions due to petroleum and natural gas consumption 2004–2014 (http://www.sis.gov.eg)

Year	Consumption of petroleum products and natural gas (million ton)	CO_2 emissions (million ton)[a]	The cost of environmental impacts on the national economy (million US$)[b]
2004/2005	49	133.5	10,680
2005/2006	50	139.4	11,152
2006/2007	53	148.5	11,880
2007/2008	60	159.0	12,720
2008/2009	63	166.7	13,336
2009/2010	67	177.0	14,160
2010/2011	68	182.0	14,560
2011/2012	72	192.0	15,360
2012/2013	73	197.0	
2013/2014	73	197.0	

[a]Excluding the consumption of natural gas in industry sector for non-energy purpose
[b]Environmental impacts from CO_2 emissions was estimated by 80 US$/ton approximately

Table 8.2 Pollutants that have reduced as a result of processing with rice straw (2010–2013) (http://www.sis.gov.eg)

Item	2010	2011	2012	2013
Rice straw which were processed	600,000	365,274	312,000	200,000
Total suspended T. S. P.	6000	3653	3210	2000
Sulfur dioxide, SO_2	41	25	21	14
Nitrogen oxides, NO_2	245	149	128	82

8.11 Conclusions

The increasing quantity of agricultural waste and its inappropriate disposal or burning especially in developing countries have always been putting press on the environmental safety and population health. Also, it also leads to increasing the global GHGs emission and increasing global warming and global climate change impacts. Thus, appropriate and environmentally friendly methods for utilizing agricultural wastes and transforming them into valuable resources is very necessary for climate change mitigation. Many methods are used increasingly to the benefit of these wastes. However, many others are required to be adopted for such purposes.

8.12 Recommendations

The following recommendations are highlighted:

(1) More studies on utilizing agricultural wastes are urgent either for generating new energy resources, for finding new uses, or maximizing the recent benefit uses for overcoming the environmental problems.
(2) Increasing awareness of the negative impacts of misusing or burring agricultural wastes is required specially these wastes are valuable and potential source of wealth.
(3) Utilizing the local farmers experience in dealing with agricultural wastes especially in their local sites is very important specially if integrated with the new scientific findings by the specialized researchers.
(4) Supporting of governments and policy making will be very beneficial to farmers to effective utilizing of agricultural wastes as a wealth source and to mitigate the potential impacts of climate changes.

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Chapter 9
Logistics of Waste Management with Perspectives from Egypt

Noha Mostafa

Abstract Waste generation in developing countries is highly increasing due to the accelerated economic growth. This raises many issues and concerns due to the high population and the improper waste management. For the Arab countries, the amount of municipal solid waste generated is about 81.3 million tons per year; less than 20% is adequately treated, and less than 5% is recycled. Another main issue is the transportation and logistics of waste. To address these issues, this chapter adopts 'reverse logistics' to explore how to manage waste and increase waste utilization efficiently. The scope of this chapter is Egypt and can be generalized to the Middle East and North Africa (MENA) region. The main interest of this chapter is to understand the role of reverse logistics in waste management and to determine the factors that influence logistics decisions and practices for waste management.

Keywords Reverse logistics · Waste management · Strategic decisions · Tactical decisions · Egypt waste · Sustainability

9.1 Introduction

Waste is some material generated by human activity, and not suitable to be used in its current form so it is discarded [1]. Waste can be divided into two main categories in terms of its source: municipal (from domestic activities such as households, offices, markets, shops, restaurants) and industrial (such as business activity and constructions). In terms of the nature of materials forming the waste, several waste streams exist such as organic waste, green waste, paper, plastics, textiles, glass, metal, minerals, ashes, building waste, and hazardous or toxic waste. In the developing countries, organic or biodegradable waste is the highest as it is unprocessed and contains high moisture and organic content that exceeds 55% in many countries [2], while the developed countries produce more industrial waste that has toxic or hazardous ingredients [3].

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One of the problems with the developing countries is that most of the people and the governments as well still think that waste is just a problem that contributes to environmental pollution and land overuse with concerns regarding hygiene and public health and are unaware of the potential of recycling and other benefits such as power generation through biomass. Hence, one of the fundamental missions in waste management is to implant the concept that waste can be not only collected and transported but also cleaned, reused, or recycled into something valuable [4]. In that sense, waste is no longer seen as just waste, but useful material that can contribute to the economic development of the country and the global ecological footprint.

The increasing population density in cities implies lower per capita cost for providing services and infrastructure [5]. A survey conducted in twenty-five megacities in 2006 ranked waste management the fourth among the main problems in major urban areas after air pollution, transportation, and general pollution [6]. It is estimated that the global solid waste generation would reach up to 2.2 billion tons per year by 2025 [7].

With the increasing environmental awareness, demand for more efficient waste management solutions and approaches has increased. In some countries, inefficient waste management has become a real crisis both socially and environmentally. In the developing countries, most waste management services serve a limited minority of the population living in the wealthier areas with rich or powerful residents; on the other side, low-income earners living in middle and poor areas do not receive adequate waste collection service, leading to the accumulation of waste in the streets and by the drainage channels [8].

In the old times, before industrialization, waste was not a big problem. However, with industrialization and urbanization, waste generation rate has increased rapidly more than nature can assimilate [9]. With the increasing dangers on the environment, the ecosystem, and public health; governments started to participate and put regulations on waste disposal and management on local and global scales [10]. With the global trend toward, sustainable development, waste management has acquired an increasing consideration. In many countries, strict legislation targeted waste disposal to reduce waste and minimize the risks to health and safety [11].

Traditionally, landfills were used as central locations for waste disposal usually by incineration or burning the waste. Incineration is suitable for organic waste, and it can reduce the waste volume by over 90%. The energy created by this combustion may be reused for power generation, but if not, then the generated heat will be dissipated in the environment causing air pollution [12]. In many developed countries, incinerators were banned by the late twentieth century due to health and environmental problems. More recently, waste generated per capita has significantly shortened the lifespan of many landfills, and it has been becoming more difficult to find suitable areas to set new landfills, especially with the conflict with the citizens and the Not-In-My-Backyard (NIMBY) culture. Hence, innovative solutions should be found to manage and reduce waste and shift the concept of waste management from being a disposal problem to a more integrated one from a lifecycle perspective. Many developed countries could significantly cut the amount of waste by encouraging better resource usage and consumption patterns and launching several waste reduction initiatives

[13]. The European Union obliged that by 2020 all the member countries should reuse and recycle at least 50% of the recyclable materials generated by the household [3]. Many countries could achieve success stories in the area of waste management such as Germany [3], Singapore [13], Sweden [14], and South Korea [15]. Some waste materials can be used as raw materials for manufacturing, which is known as 'waste exchange' [16]. Other waste such as food waste can be reused for soil enrichment for planting and farming activities.

The term 'logistics' involves the activities of moving and handling goods and services, including planning, scheduling, resource assignment, distribution, routing, collection, sorting, preprocessing, and monitoring, to satisfy a required need in an efficient way in terms of cost and time. 'Reverse logistics' is a more recent topic related to damaged or defected goods that should be returned to the distributor or the manufacturer. The main difference between logistics and reverse logistics is the direction of goods' flow. In reverse logistics, the flow is from the point of consumption toward the point of origin, to recapture value or for proper disposal [17]. In that sense, municipal solid waste (MSW) recycling can be classified as an application of reverse logistics [18].

Recycling requires many logistical activities such as collection, transportation, separation, sorting, and cleaning. Waste separation at source was a revolutionary concept that makes it easier to perform recycling. It means separating waste at the household by dividing the trash cans into different streams mainly for two categories: dry waste (e.g., glass, cans, wood) and wet waste (e.g., food and organic waste) [19]. Unfortunately, the culture of waste separation at source is still not applied in Egypt and most of the MENA region and African countries as well, which makes it more difficult to perform recycling and gives the opportunity to informal waste pickers to search for some material to sell for recycling.

This chapter tries to capture the role of government and the involvement of the private sector and other stakeholders in waste management and to review the current practices for waste management in developing countries with a focus on reverse logistics. It also addresses the implementation of reverse logistics in waste management, and the works addressed this connection. Also, it elaborates on the topic of sustainable waste management and the situation in Egypt is presented as a representative country of the MENA region.

9.2 Waste Management and Reverse Logistics

Reverse logistics support the circular economy concept by shifting from the open linear model of material flow to a closed material–energy cycle, which leads to a significant reduction in the economy entropy and the improvement of utilization rates [20]. Returning material in the supply chain requires some processes, such as separation and sorting to start producing new products with the same or even less value [21].

In the 2000s, some researchers observed the similarities between reverse logistics networks and waste disposal networks [22]. Hu et al. [23] argued that reverse logistics could improve and protect the environment from hazardous materials through controlling waste flow for reuse or disposal. Product recovery and recycling gained high importance since the 1980s, due to the low landfill capacity, the increasing cost of disposal, and the restrictions on waste transportation between cities. All of these issues forced governments and communities to develop programs that support recycling, especially for paper, glass, and plastics [24], while organic waste is usually converted to compost and can be used for biogas production [25]. The complexity of decisions on recycling is determined by many factors, such as local and regional regulations, oil prices, the varying interests of different stakeholders, and level of awareness. To improve the whole process performance, insights into the system are required [26]. With good management and implementation of reverse logistics in waste management, a significant impact can occur economically and environmentally [27].

Optimization of logistics processes of waste management has been receiving increasing interest to support various types of value recovery of different materials including a waste reduction from resources. Carter and Ellram [28] argued that waste reduction should be the ultimate goal of the reverse logistics process through designing more eco-friendly products. The three R's for waste: reduce, reuse, and recycle, help to cut down on the amount of waste and hence conserving energy and natural resources [29]. Waste reduction can be achieved through better management and more responsible consumption. Waste reusing can maximize waste value and resource utilization. When reusing is not possible, recycling can be used to recover products in the best possible way or to make new products. Waste that cannot be reused or recycled can either be used for energy generation or simply enter the final waste stream. Hence, reverse logistics in waste management is more than reusing and recycling materials, re-designing of products and packaging, energy consumption reduction, pollution reduction from manufacturing and transportation activities have a significant impact on the process [30]. Figure 9.1 shows the logistics and reverse logistics flows of waste management.

However, some researchers classify such activities within the 'green supply chain' framework, not reverse logistics; see, for example, Graczyk and Witkowski [20] and De Brito and Dekker [31]. On the other side, some works considered reverse logistics as a part of a green supply chain, not an independent area [32].

Another important application for reverse logistics in waste management is for construction waste. Construction projects usually lead to the high production of waste and emissions. Construction waste is a single waste stream that forms one-fourth to one-third of total disposed waste in many countries [33]. However, construction waste is relatively easier to handle and process compared to municipal waste as its sources can be easily identified, and the composition of the waste material is well-defined. Many researchers have been interested in this topic; Tischer et al. [34] found that implementing a planned waste management policy can reduce the economic and environmental impacts regarding reusing and recycling. According to them, waste can be sorted on site as the collection cost of the construction waste

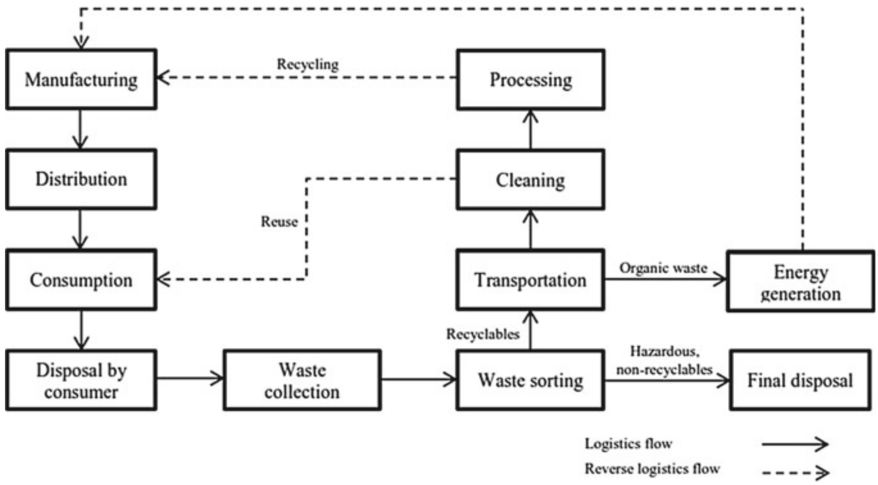

Fig. 9.1 Logistics and reverse logistics flows of waste management

cannot compensate the cost increase in disposal fees; this strategy can improve the efficiency of logistics by approximately 9%.

Other studies about reverse logistics in waste management have covered several applications such as waste generation and disposal in grocery stores [27], offshore petroleum logistics [35], healthcare institutions [36], and industrial waste [37].

Logistics decisions are generally classified into strategic, tactical, and operational decisions based on the time horizon of their impact. Strategic decisions have long-term effects that can last for years. Tactical decisions have medium-term effect; finally, operational decisions have a short-term effect [38]. Since product recovery networks are similar to waste disposal networks from a supply chain perspective [22], then the decision classification for logistics is valid for waste management processes. Shipping material to disposal sites and treatment centers can be seen as an extension of reverse logistics, so integrating waste management processes within the overall logistics process can reduce the negative transportation impacts [39]. Dealing with such complex decisions can be supported by using operations research (OR) models [40]. The decision-making problem is decomposed into several sub-problems with different scopes and levels. According to Ghiani et al. [40], waste management system (WMS) can be decomposed into two sub-systems: a regional WMS and a collection WMS.

9.2.1 Strategic Level

For waste management, at the strategic level, decisions are made to determine the network design of the recycling network that includes collection, separation, sorting, and processing [26]. The separation step is sometimes performed in the same time and location of waste collection, and in other cases, separation is performed in an equipped separation center. After that, waste is sorted and transported to treatment facilities for recycling. Treatment processes vary according to the type of waste. Figure 9.2 depicts a generic logistics model for a recycling network. The network design should be determined in terms of number, locations, and capacities. Network design decisions belong to the regional WMS.

Halldorsson and Skjott-Larsen [41] identified two main mechanisms for reverse logistics: centralized and decentralized. In a centralized network, a single organization is responsible for the collection, separation, sorting, and transportation of the material. In a decentralized network, several organizations are involved in this process. In many countries, business organizations are obliged to do pre-treatment for waste before disposing of it, with the objective of reducing its volume, reducing its hazardous nature, and facilitating its handling.

Location models are used for such strategic problems to decide the number and locations of the different facilities taking into account single or multiple time periods, various problem characteristics and single or multiple objectives. Barros et al. [42] proposed a model to determine the number, locations, and capacities for the depots and cleaning facilities for sand waste recycling. Louwers et al. [43] developed a location–allocation model for carpet waste recycling network. Huang et al. [44] developed a fuzzy model by using integer programming to make decisions on the expansion of recycling facility. Mitropoulos et al. [45] used mixed integer programming to solve a network design problem with central solid waste treatment facilities, sanity landfills, and transfer stations. Innovative approaches for waste management in urban areas were addressed in the work by McLeod and Cherrett [46]; these approaches include waste delivery to out-of-town facilities, combining commercial and household waste collection, using multi-modal transportation, and using smart bins technology. Gomes et al. [47] developed a mixed integer linear programming model to determine the locations for collection and sorting facilities for a Waste Electrical and Electronic Equipment (WEEE) recovery network. Budak and Ustundag [48] proposed a model for reverse logistics optimization for waste management in health institutions. This model can build a network for waste collection and disposal. Mixed integer programming was used to determine the optimal number of facilities

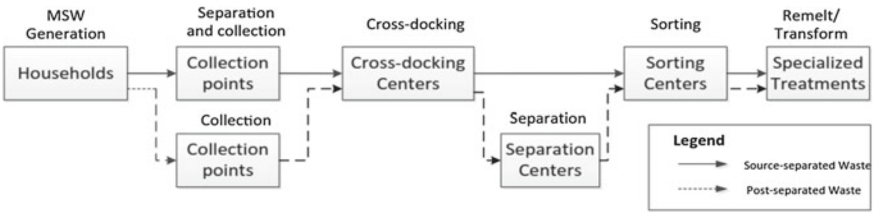

Fig. 9.2 Logistics model for recycling network [26]

for waste management and their locations (storage, sterilization, burning, grinding), by taking into account the changes in waste amount.

Since waste consists of various waste types, then the network can be regarded as a multi-commodity problem. Multi-commodity problems have been studied in hundreds of logistics and supply chain works [49]. However, multi-commodity problems in the context of waste management logistics network were seldom addressed. It can provide a good opportunity for future works on recycling and waste separation which has an impact on the whole network design.

9.2.2 Tactical Level

The main issues at the tactical planning level are waste collection and sorting; decisions should be made about the types of waste to be collected, the number of waste streams, the types of collection, and the types and number of vehicles required. Generally, there are two locations for waste collection: curbside or central collection points [26]. In the UK, for example, three common schemes exist:

- Curbside sorting: The recyclable waste is separated into different compartments of a special collection vehicle at the curbside.
- Single stream co-mingled: Material is collected in a single compartment vehicle, and the sorting occurs at a material recycling facility.
- Double stream co-mingled: Sorting is performed at the household where they are asked to sort the recyclables into different containers, usually one for paper and fiber and the other for plastics, glass, and cans. They are then collected into one vehicle that has different chambers.

It is difficult to generalize one model as a best practice, as it depends on many factors related to the country and the city. For example, in Denmark, using curbside collection and sorting could increase the recycling rate by 25% and reduce the amount of landfilled waste by 11% [50]. While in the USA, it may be costly to adopt such method due to the limited amount of waste per residence in some states compared to the distances traveled by the vehicles [51]. Since the 1990s, underground and semi-underground systems have been introduced for waste collection in urban areas. In these systems, waste containers are positioned underground usually in the form of a permanent infrastructure network and can be incorporated with automated vacuum collection (AVAC) systems. These systems have several advantages from logistics and environmental perspectives. Success stories of such installations exist in many cities such as Roosevelt Island, Barcelona, Wembley, Leon, Yas Island, and Mecca [6].

Typically, tactical decisions are modeled using flow allocation models and fleet composition models. However, research in this aspect of waste management is still relatively limited [26]. Logistics outsourcing or what is known as third-party logistics (3PL) is another important problem that can be looked at from the strategic or tactical point of view. In many countries, waste management networks involve outsourcing

(a) Stress compact (b) Rear loader single compartment

(c) Rear loader multiple compartment (d) Side loader

Fig. 9.3 Some vehicles types used for garbage collection

decisions. As more operations are outsourced, the importance of networking and negotiation through business relationships increases [52].

An important logistical decision is to determine the optimal fleet size and type [53]. Different types of vehicles can be used for waste collection. Trucks with a pressing function are commonly used in Europe and are used to collect paper waste, plastic waste, or metal waste. The pressing function increases the vehicle capacity by 150–200%. Trucks can have single or multiple compartments. They can be rear loaded or side loaded and can be equipped with vacuum pipes. Figure 9.3 shows different types of vehicles.

9.2.3 Operational Level

Waste collection is one of the major and costly operational problems in waste logistics, representing over 70% of the total cost [54]. Operational decisions are required to make decisions on vehicle routes, collection frequency, and the dynamic characteristics of the problem. It is important to make a balance to fulfill waste collection requirements while reducing the number of visits by waste collection vehicles. This may lead to a reduction in total vehicle mileage, traffic congestion, and CO_2 emissions. Although the research on vehicle routing problem (VRP) started since the 1960s, route optimization in waste management is relatively a new research topic that takes into consideration vehicle size, type, capacity, fuel type, engine efficiency, and emissions [55]. One of the bad practices in the waste collection, especially in developing countries, is that the vehicles are sent to collect waste randomly from dispersed areas, which leads to an increase in the traveled distance [56, 57]. The routing model can be modeled with an arc routing approach or a node-routing approach. Curbside collection is usually modeled as an arc routing problem in which all the arcs (streets) must be visited by the vehicle. Two main methods can be used for solving the VRP and finding the optimal routes; mathematical programming and metaheuristics such as genetic algorithms, Tabu search, simulated annealing, and ant colony optimization [58].

Researchers have been interested in this research topic. Amponsah and Salhi [59] proposed a constructive heuristic to solve the waste collection and transportation problem in the developing countries, by taking into account economic and environmental aspects. Sahoo et al. [60] argued that it is necessary to minimize the operational expenses and to optimize the fleet size to achieve an improved WMS. As a node-routing problem (NRP), Baptista et al. [61] used this model to solve the problem of collecting recycling paper containers and proposed a heuristic procedure to solve it. Bautista et al. [62] modeled the waste collection problem as NRP with taking forbidden street turns into account due to traffic signals and traffic jam. Nuortio et al. [57] solved a mixed waste bin collection problem by using a variable neighborhood search (VNS) metaheuristic. Karadimas et al. [63] used ant colony optimization metaheuristic to find the optimal routes for the waste collection vehicles. Muyldermans and Pang [64] used a multi-compartment vehicle routing problem (MCVRP) to model separate collection and used a local search procedure to solve the problem. Ramos and Oliveira [65] modeled a waste collection network for recyclable packaging with multiple depots, where the areas served by each depot should be pre-defined along with the collection routes. Mora et al. [66] modeled the problem as a capacitated arc routing problem (CARP) and used a heuristic procedure to obtain solutions in a reasonable computational time. The authors considered the economic and environmental impacts as elements for the validation and evaluation of the proposed solutions. Moustafa et al. [67] proposed a solution for the VRP for waste collection in Alexandria, Egypt. They have developed a geographic information system (GIS)-based model to solve the problem by using the TransCAD software. The developed model can be used as a spatial decision support system (SDSS) to test different scenarios for solid waste collection to find the best scenario that can improve the overall logistics system's performance.

The collection is traditionally performed by the municipality, but in some cities, it may be outsourced to private companies or contractors; for example, this strategy proved a big success in Kuwait [68]. However, waste collection is still a problem in many developing countries. For example, Ayininuola and Muibi [69] studied waste collection in a large city in Nigeria, and they reported that only 54.5% of the waste generated in the poor areas was collected, which leads to high air and water pollution rates. For an overview of the waste collection status in African countries, the reader is referred to the work by [3].

Many works addressed the operational decisions on waste logistics; Sonesson [70] proposed a model for calculating the fuel consumption for collection and transportation of recyclables in Sweden. He found that fuel consumption is high due to separated waste streams and delivery routes, which can have a negative impact economically and environmentally.

9.3 Sustainable Waste Management and Green Logistics

With the global trend toward sustainable development, logistics activities should fulfill the adequate economic, social, and environmental levels. The objective of sustainable development is to meet the needs of the present generation in ways that are economically viable, environmentally adequate, and socially equitable without compromising the ability of future generations to do the same (according to Mostafa and Negm [71]. The three aspects can be defined as follows:

- Economic sustainability is a way to achieve long-term economic growth by taking into consideration the product lifecycle.
- Environmental sustainability is to minimize the negative effect on the environment and natural resources while functioning properly.
- Social sustainability is to achieve development without depleting the human and social resources but contributing positively to the community welfare.

Implementing these concepts in business practice are now gaining increasing interest, global market trends, governmental regulation, and consumers' pressures have stimulated many efforts being exerted to spread the awareness about sustainability concepts, the ecological crisis and social responsibility [72]. Hence, innovative solutions are required in all sectors to manage the resources sustainably; energy and waste should have priority for such implementation [73]. Sustainable development can be addressed in the context of reverse logistics and waste management from several points of view. According to Williams et al. [74], waste management increases the employment rate and revenues, while widening the social and technological impact resulting from the efficient waste management policy. It can be seen as a multi-dimensional process that can reduce poverty and inequality and negative environmental impacts.

Many legislative actions were taken to drive organizations to utilize reverse logistics and to ensure the compliance with the sustainable-oriented new rules. A good example is the European Union directives on packaging waste. The first directive 85/339/EEC was issued in 1985 to set rules on producing, using, disposing, and reusing containers of liquids. A second version was issued in 1994 to provide a higher level of environmental protection. Later amendments were made in 2004, 2005, and

2013 to increase the recovery and recycling targets. The latest version was issued in 2015 to adopt significant reduction of lightweight plastic bag consumption [75].

Another issue is road transportation of waste that plays a significant part in the waste management logistics process. It has functional importance, but at the same time contributes to the total cost and has a significant effect on the environment. In the future, alternative transportation modes, such as water and rail, may be used to reduce the economic and environmental impacts [76]. In that sense, a proactive and collaborative approach would be needed to integrate decisions on land use, transportation, and waste management logistics. Generally speaking, the environmental impact of the logistics activities is more significant in urban areas, the research on city logistics is largely focused on the forward logistics, while little research was dedicated to the impact from the reverse logistics point of view.

An increasing number of works address the topic of sustainable waste management. Pourmohammadi et al. [77] developed an optimization framework for the business-to-business network for a sustainable material treatment. The objective of that model is to minimize the operational and environmental costs of waste exchange and by-product materials, mathematical programming and a genetic algorithm metaheuristic were used to solve a case study aluminum waste in Los Angeles. Tralhao et al. [78] used multi-objective modeling to locate multiple compartment containers for waste sorting in urban areas.

Bing et al. [79] developed a model to choose the most suitable separation method for plastic waste in the Netherlands. The model uses mathematical programming to optimize the reverse logistics network design to achieve a sustainable and efficient recycling system by minimizing the transportation cost and the environmental impact. The results of this chapter have shown that post-separation incur higher costs and higher environmental impact due to the limited number of separation centers compared to the number of cross-docks for source separation. Ramos et al. [80] proposed a multi-objective model for recyclable waste collection system to take into consideration the three aspects of sustainability. Groot et al. [81] proposed a plastic waste collection model which takes into account the collection cost and CO_2 emissions. Ferri et al. [82] studied solid waste management problem by taking into consideration economic, environmental, social, and legal criteria. Kaliampakos [6] addressed sustainability challenges in modern cities and the potential for underground utilization in waste management.

Small and medium enterprises (SMEs) often have the challenge to obtain affordable waste handling and recycling services [83], and it is suggested for them to coordinate operations across various waste streams to improve the performance of waste management policy. In the developed countries, many companies were established to provide customized collection system for business to allow better management for the recyclable waste and a better environmental benefit through increasing the recycling rate and reducing the amount of landfilled waste. Another potential practice for sustainable waste management is using hybrid trucks in waste collection. In 2008, Sweden started to adopt such trucks for curbside collection [84].

From this discussion, it can be seen that it is needed for governments, private sector, and community to collaborate in developing solutions that promote sustainable

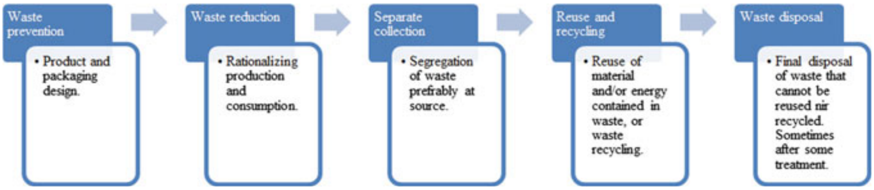

Fig. 9.4 Suggested activities for sustainable waste management logistics processes

waste management programs, especially in the developing countries. The first step in achieving this endeavor is to redefine the structure of the logistics network by accommodating the social and environmental aspects associated with cost reduction in waste management decisions and activities. According to Gutowski [30], responsible management strategies can streamline the logistics of waste management and the recycling process. Figure 9.4 gives the process of suggested activities for sustainable waste management logistics processes.

9.4 Logistics of Waste Management in Egypt

In this section, the status of logistics of waste management in Egypt is overviewed as a representative country of the MENA region. Generally, the problems of waste management are more significant in cities and urban areas, not rural ones. The quantity and organic content of waste generally compose 56% of the total waste. However, organic waste is much less in the rural areas since the villagers traditionally use a big portion of it for other activities such as feeding animals and use it as fuel for ovens. Hence, while rural areas comprise about 60% of the total population, they only dispose around 30% of the total amount of solid waste nationwide. According to Ojok et al. [85], per capita waste generation in developing countries is about 0.3–0.6 kg/day. In 2012, 89.03 million tons of solid waste was generated in Egypt; the per capita solid waste generation in 2012 was 0.7–1.0 kg/day in urban areas compared to 0.4–0.5 kg/day in rural areas, while the official waste collection coverage in urban areas is 50–65% compared to 0–30% in rural areas [86]. The destination for solid waste in Egypt is illustrated in Fig. 9.5. According to a report by the Egyptian Environmental Affairs Agency (EEAA) [87], the quantity of uncollected waste in Egypt reached a total of 25 million m^3.

The composition of MSW in Egyptian urban areas is shown in Table 9.1. It can be seen that organic waste is the main component; other material includes construction waste and hazardous waste.

Cairo, the buzzing capital of Egypt, has an area of 528 km^2 with a population of about 22.8 million in greater Cairo which represents about 25% of Egypt's population [89]. Due to the rapid growth in population and increased urbanization, daily waste generation in Cairo was approximately 15,000 tons [90]. The average density of

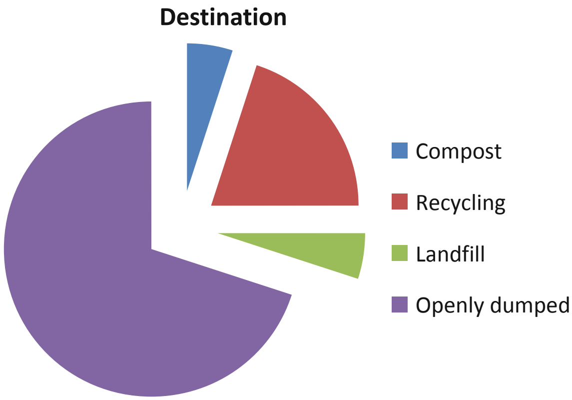

Fig. 9.5 Main destinations for solid waste in Egypt

Table 9.1 Composition of MSW in Egyptian urban areas [88]

Waste composition	Percentage (%)
Organic waste	60
Paper	10
Plastic	12
Glass	3
Metals	2
Textiles	2
Other	11

solid waste in Egypt is about 300 kg/m^3, which is significantly higher than that found in developed countries. This is an important factor that is used to determine the number and capacity of the required waste storage and collection facilities and trucks. Usually, truck capacity only takes weight into consideration. However, due to the high waste density in Egypt, the effectiveness of compaction vehicles is minimized, and sometimes they break down.

With the rapid expansion of buildings, the increasing population, the increasing migration to Cairo, it is quickly running out of landfills. Hence, it is necessary to reduce landfilling by following more advanced waste minimization and management strategies. One of the biggest problems in Egypt is the illegal waste pickers or salvagers who collect and sort garbage from bins and landfills manually and without any safety equipment. Many of the poor and unemployed do this activity to make a living, especially when they are low-to-medium skilled. A study from 2007 found that in developing countries, about 1% of the urban population survives by salvaging recyclables from waste [4]. There is no accurate data can be found regarding the number of waste pickers in Cairo, but the number is undoubtedly significant considering the high poverty and unemployment rates. Illegal waste picking has a negative impact as waste pickers scatter the waste to find the recyclable material, and this causes garbage scattering out of bins in the streets and increases the cost and time of waste collection by municipal trucks. Also, these pickers usually use carts pulled by horses or donkeys to transport the recyclables they collect, and this leads to traffic problems in addition to littering dung on streets [4]. Several attempts were made by governments to stop such activities or even formalize them. One of the successful practices was performed in Brazil where a national program was launched to incorporate waste pickers into official local WMS. The project was funded by the World Bank with an amount of 2.73 million dollars and was implemented in the period 2010–2014 [91]. This project was accompanied by economic development and provision of low-cost housing and education, hence achieving great improvements [92].

The concepts of waste reduction and waste separation at source are still not adopted on a country-wide scale. Very few examples exist in new cities, closed compounds, private universities, and some hotels. It is required to make a major shift in the mindsets of the public and private sectors and the community to adopt such practices. The recycling rate in Egypt is relatively low compared to this in Europe; for example, recycling rates in the UK is about 31% [93]. In developing countries, recycling is almost performed through informal sector; usually unregistered small-scaled and labor-intensive factories with low technology. According to Chvatal [94], such factories depend on manual picking and sorting of recyclable and reusable material from the streets and landfills by low-paid labor, most of the labor are children, which increase safety and health risks. In Cairo, the informal waste recyclers recover about 80% of the recyclables [95]. Usually, waste pickers do not sell the recyclables directly to the factories, Fig. 9.6 shows the process flow for the illegal recyclable waste picking.

Waste quantities are linked to population and economic growth. According to the World Bank, the economic growth of Egypt has witnessed drastic fluctuations during the past 20 years (Fig. 9.7). Waste generation rates are relatively high due to consumer behavior and the increasing population. This economic instability has led to increasing prices and high poverty rates and unbalanced income levels.

An excessive solid waste generation without proper waste treatment causes several negative impacts and leads to social and environmental problems. In several streets of Cairo, one can see piles of trash by the sides of the streets, especially in low- and medium-income residential areas. Generally, waste collection is performed by the government, but with the lack of enough budget and resources, it is difficult to implement effective waste management policies. As in most of the developing countries, the allocated waste management budget is not enough since the government dedicate budget to other pressing issues. The vehicles used for waste collection are usually old

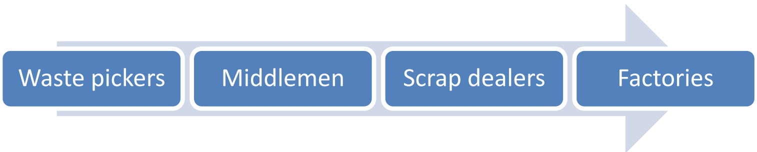

Fig. 9.6 Illegal waste-picking process flow

Fig. 9.7 Economic growth of Egypt during the past 20 years [96]

and not properly equipped. During waste transportation, the trucks can overflow and litter the city with trash. Lack of technical expertise and waste management planning can be even dangerous as waste can contain toxic and hazardous material [97], and this is getting worse given that the main disposal method for waste, in Africa in general, is open landfills, with no proper environmental control [98]. Such landfills cause considerable land degradation and contamination of underground water sources. In the 2000s, there were some attempts to contract with private companies to collect waste from residential areas with fees billed directly to the clients, but later most of those contracts were not renewed. However, several laws and regulations were issued for waste treatment. For example, according to Law No. 4/1994, incineration is a mandatory treatment for hospital waste. The government has built compost factories as a potential solution to make use of waste, but the established plants have not operated efficiently and could not make profits to cover the initial cost.

According to Said et al. [88], there is good potential for biomass energy generation and utilization in Egypt. In 2010, Egypt adopted an ambitious plan that by 2020, 20% of the produced electricity will be generated by using renewable energy resources [99]. Biomass resources include MSW, agricultural residues, animal wastes, and sewage wastes. Energy can be recovered from the organic fraction of MSW through two methods: thermochemical conversion through incineration and biochemical conversion through anaerobic digestion.

To summarize the status of waste management in Egypt as a representative country of the MENA region, it can be said that despite the national and local efforts to deal with the solid waste management crisis. The performance of logistics of waste management is not efficient in terms of waste collection, handling, storage, treatment, and disposal with major environmental and public health risks. It is necessary to make adequate plans and legislation, and it should be taken into consideration to integrate the informal sector with the official waste management sector. A key factor in any new WMS is raising the people awareness about the benefits of waste separation at source and waste reduction practices.

9.5 Conclusions and Recommendations

Increased population growth rate, rising urbanization, and low public awareness are challenges that face many developing countries to establish sustainable development plans. In terms of waste management, this has led to several problems such as high waste generation rates and inefficient collection, transportation, and waste disposal. Several areas do not receive any waste collection services which lead to hazards on public health and on the environment. Reverse logistic activities in developing countries suffer from the economic and legislative conditions. The recycling rate in Egypt is still low compared to the rate in the developed countries. Incorporating reverse logistics in waste management activities will have a significant impact on minimizing waste amount and emissions. Planning these activities should take into consideration economic, environmental, and social considerations in order to establish sustainable policies. According to Pumpinyo and Nitivattananon [100], the main barriers that affect sustainable performance in waste management can be categorized in five categories: Finance, market competition, management and technology, labor, and governmental policies and regulation.

For the three decision levels in logistics, the following recommendations can be suggested for an effective WMS in Egypt as well as other African and MENA countries:

- Developing an integrated sustainable waste management policy;
- Establishing efficient reverse logistics networks for waste management;
- Greening the waste sector based on the international standards of waste hierarchy;
- Improving the efficiency of collection methods, coordination and scheduling;
- The national strategy should promote the 3Rs: reduction, recycling, and reusing;
- WMS reformation and engagement of the informal sector within the official system;
- Develop proper capacity plans and vehicle routing plans;
- Raising the public awareness about waste reduction and recycling;
- Adopting product lifecycle approaches;
- Adopting technology-based treatment and disposal;
- Imposing legal issues regarding manufacturers' responsibility for packaging and post-consumer waste;
- Collaboration with universities and research institutions to develop better waste management plans.

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Chapter 10
Solid Waste Management in Palestine

Eyad Yaqob

Abstract There is a significant increase in the urban population in developing countries, such as Palestine, and this poses a major challenge to the Joint Service Councils (JSCs) for solid waste management in Palestine. The problems associated with solid and hazardous waste management in developing countries are diverse and complex. Rapid development, urbanization, population growth, and problems related to the effective management of solid waste have greatly escalated. There are five distinct aspects of solid waste management: identification and classification of source and nature of waste, separation, storage, and collection of waste, waste transportation, treatment (including recovery of resources) from waste, final disposal of waste. The critical waste management issues that Palestine is challenged include stop increasing waste generation and saving landfill space and consequently lengthening the lifetime of the landfill sites. The process of sitting and building of new landfill sites entail, like in other countries, time-consuming processes, and require a long time in general, or rather difficult especially in Palestine if considered territorial dispute and political situation. Under such circumstances, it is required to know the actual data for solid waste situation as accurately as possible and to estimate the future waste quantity and quality in order to establish a precise policy on waste management and facility construction plan. The purpose of this chapter is to focus on the solid waste equipment management and how to plan the future needs of waste collection vehicles in Palestine. The study has determined that the waste collection vehicles which production before 2010 are out of duty and expendable vehicles and must be fully replaced and vehicles produced between 2011 and 2015 have 50% workable and vehicles of 2016 and higher are considered new and do not need to be changed. The study showed that in 2022, Palestine needs 97 garbage collection vehicles to meet the expected deficit in collection vehicles. The expected waste quantity will reach 2353 tons/day. The total severed population in 2022 is 3,139,341 (65% of the Palestinian population at that time), and the Unit Generation Rate is 0.75 kg/person/day.

Keywords JSC · Palestine · Landfill · Solid waste · Waste management

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10.1 Introduction

10.1.1 Current Status of SWM in the West Bank

The per capita municipal waste generation in the West Bank/Palestine is 0.73 kg/d, and the estimated generated waste is 2190 t/d (799,350 t/y) [1]. Currently, the achievement of proper and comprehensive solid waste management in Palestine is facing many challenges at different levels; legal, organizational, technical, cultural levels, etc., in addition to the difficult political situation represented by limited Palestinian access and control on lands and resources [2].

From the public awareness aspects, we can say that we still suffering from low level of public awareness and realization toward the importance of keeping our environment safe and clean, as well as the necessity of keeping paying for the waste service which means more pollution and deterioration of natural resources (soil, water, air) [3].

Recently, solid waste management becomes a critical issue, not only for its environmental impact but also for economic and social impacts [4]. Though the Palestinian authorities did many efforts and achievement, such as launching many legal documents (local authorities bylaw No (1), environmental law [5], public health law (2004), solid waste management bylaw, joint service council bylaw (2016), guidelines for solid waste management tariff, in addition to many other achievement during last 6 years, including construction of regional sanitary landfill in the south (Alminyeh), receiving the approval on construction of Ramoun Landfill for the middle area, expansion of ALfukhari landfill in Gaza strip, 52 open dumpsites were closed in the West bank since 2010, and rehabilitation of the closed dumpsites in northern areas and Al-Aghwar, all of these achievements contributed significantly in reducing the environment and health impacts of open dumpsites. The MoLG continue its support to the JSCs toward achieving proper and safe waste disposal in many communities [5].

Regarding waste composition, many analysis experiments took place as pilot studies in the Sanitary landfills location in Palestine [6]; Alminyeh and Zahret Alfinjan and Jericho Landfill. Based on the analysis results, it appears that Organic Fraction was between 50 and 55% which represents the biggest percentage of total generated quantities. Other fractions including plastic, glass, metal, and cardboard represent the remaining 45–50% of the generated waste [7].

Based on the collected database from the Joint Services Councils (JSCs) (2017), the collection and transfer fees is ranging between 19.21 US$/Ton in Qalqilyea and 56.32 US$/Ton in North East and South East Jerusalem, regarding disposal, the final destination of 82% of the collected waste is the sanitary landfills, where 17% is going to the open dumpsites, and 1% is recycled.

10.1.2 JSCs for SWM

There are 13 JSCs responsible for solid waste management in the West Bank. Twelve of the JSCs are responsible for the solid waste collection; nine of them are responsible for the waste collection and transferring only, and three of them are responsible in addition to the collection for managing the landfill sites; these JSCs are Jenin JSC, Jericho JSC, and Ramallah JSC (in the future after establishing Rammun Sanitary Landfill). And one of the JSC, which is Hebron and Bethlehem Higher Council, is responsible for managing Al Menia Sanitary Landfill including its composting facility and sorting facility, in addition to one medical facility and two transfer stations, this JSC is not responsible for waste collection, and Table 10.1 summarizes the responsibility of the 13 JSCs [5].

The 12 JSCs cover 63% of the total LGUs in the West Bank and 54% of the total population, while the remaining areas are served by the LGUs.

Table 10.1 Responsibilities of the JSC [8]

No.	JSC	Collection	Transferring to the TS or to the LF directly	Transfer station	Transferring to the LF through the TS	Landfill site
1	Hebron JSC	Yes	Yes	Menia	Menia	Menia
2	Bethlehem JSC	Yes	Yes	Menia	Menia	Menia
3	Jericho JSC	Yes	Yes	No	No	Yes
4	Ramallah JSC	Yes "***In the future***"	Yes "***In the future***"	Yes "***In the future***"	Yes "***In the future***"	Yes "***In the future***"
5	N&NW Jerusalem JSC	Yes	Yes	No	No	No
6	NE&SE Jerusalem JSC	Yes	Yes	Yes	Menia	Menia
7	Salfit JSC	Yes	Yes	No	No	Controlled dumpsite
8	Jenin JSC "Zahrat Al Finjan"	Yes	Yes	Yes	Yes	Yes
9	Nablus JSC	Yes	Yes	Yes	Yes	No "Jenin JSC"
10	Tubas JSC	Yes	Yes	Yes	No "Jenin JSC"	No "Jenin JSC"
11	Qalqelia JSC	Yes	Yes	Yes	Yes	No "Jenin JSC"
12	Tulkarem JSC	Yes	Yes	Yes	Yes	No "Jenin JSC"
13	Hebron and Bethlehem Higher JSC "Al Menia"	No	No	Yes	Yes	Yes

10.2 Data Comparison of the 12 JSC

10.2.1 Service Coverage

The service of the 12 JSCs covers 63% of the total number of LGUs in the West Bank and 54% of the total population (Table 10.2 and Fig. 10.1) [9]. Tubas JSC and Salfit JSC are providing the service for all of their planned areas. No service is provided by Ramallah JSC, and low service percentages were found in Nablus JSC, NE&SE Jerusalem JSC, and N&NW Jerusalem JSC. Low percentages of service coverage in Nablus JSC refer to the weak capability for service expansion due to the lack of collection vehicles; the available collection vehicles at the JSC are very old and work more than one shift per day. And the low percentages in NE&SE Jerusalem JSC and N&NW Jerusalem JSC are because those JSCs were newly established [10].

10.2.2 Amount of Collected Waste

The daily waste generation per capita can be known by dividing the daily collected waste by the served population (see Table 10.3). The average daily generation of solid waste in the 12 JSC areas is 0.73 kg/capita (Table 10.3). The highest waste

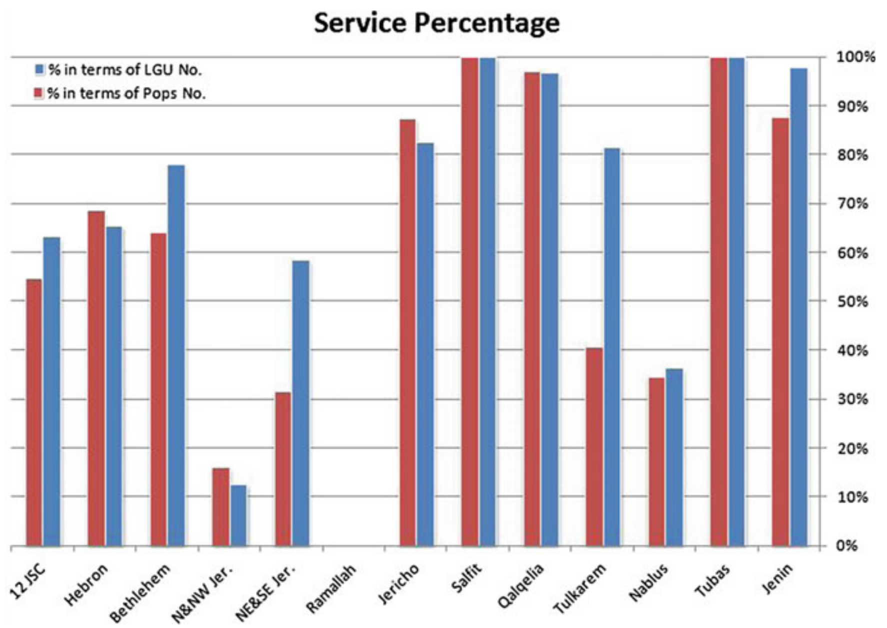

Fig. 10.1 Service coverage percentage in the 12 JSC areas

Table 10.2 Service coverage percentage in the 12 JSC areas [8]

1	Service percentage													
#	Item	JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
1.1	No. of targeted LGU	93	10	58	27	30	19	17	68	12	16	36	26	**412**
1.2	No. of served LGU	91	10	21	22	29	19	14	0	7	2	28	17	**260**
1.3	Service percentage in terms of LGU No. (%)	98	100	36	81	97	100	82	0	58	13	78	65	**63**
1.4	No. of targeted population	314,010	57,321	392,427	185,200	113,594	70,000	61,176	370,000	105,693	52,681	221,802	709,965	**2,653,869**
1.5	No. of served population	274,820	57,321	135,137	75,000	110,134	70,000	53,405	0	33,282	8361	141,693	486,610	**1,445,763**
1.6	Service percentage in terms of population No. (%)	88	100	34	40	97	100	87	0	31	16	64	69	**54**

Table 10.3 Collected quantities and daily waste generation rate in the 12 JSC areas [8]

2	Collected quantities													
#	Item	JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
2.1	Annual collected quantities (ton)	85,837	13,113	30,600	21,984	31,025	24,000	13,500	0	13,200	2500	46,552	105,321	**387,632**
2.2	Daily collected quantities (ton)	235	36	84	60	85	66	37	0	36	7	128	289	**1062**
2.3	Daily collected waste/person (kg/c.d)	0.86	0.63	0.62	0.80	0.77	0.94	0.69	–	1.09	0.82	0.90	0.59	**0.73**

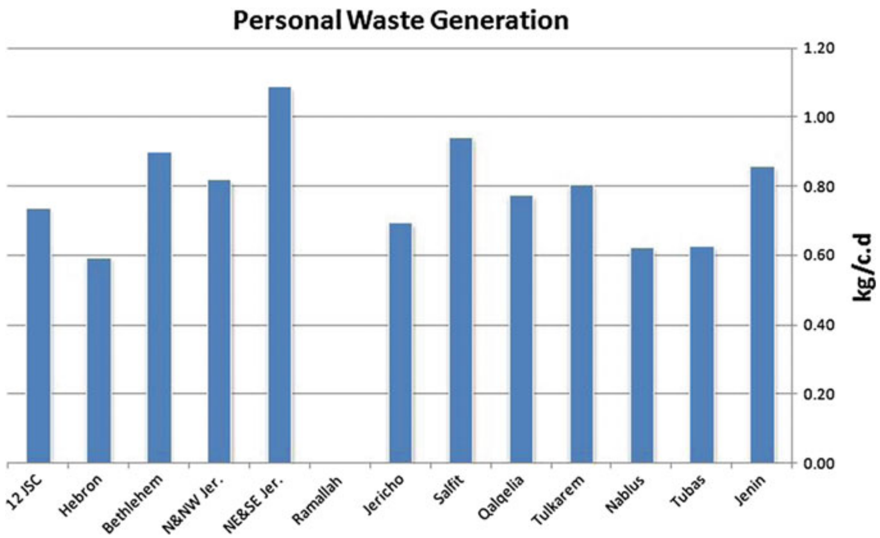

Fig. 10.2 Per capita waste generation rate in the 12 JSC areas

generation rate is in NE&SE Jerusalem JSC area, and the lowest rate is in Hebron JSC area (Fig. 10.2) [11].

10.2.3 Collection Vehicles' Capacity

The capacity of the collection vehicles to handle the generated waste is measured by dividing the total weight capacity of all the collection vehicles used by each JSC by the daily collected quantity of waste. It was assumed that the weight capacity of the compactor truck is 0.65 of its volume, and for the dumpster trucks, it was assumed to be 0.25. Table 10.4 shows that Nablus JSC has the lowest vehicle capacity to handle the generated waste; therefore, Nablus JSC vehicles work two shifts per day to cover the whole serviced area. Jericho JSC has the highest vehicle capacity to handle the generated waste according to Table 10.4 [8].

To assess the need for additional collection vehicles for each JSC, other factors shall be considered which are:

1. The density of the area, so the truck can be filled and emptied more than once a day in the dense area, while in the wide and low dense areas, where the transportation of the waste takes a long time, the truck may not be fully filled (this shall be considered in Jericho JSC area).
2. The status of the collection vehicles (Fig. 10.3).

Table 10.4 Available truck capacity and the daily collected quantities in the 12 JSC [8]

#	Item	JSC												
3	Truck capacity													
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
3.1	No. of collection trucks	34	4	5	11	12	8	16	13	4	1	20	27	**155**
3.2	Volume of collection trucks (m^3)	5–25	4–12	8–12	5–13	3–8	6–12	2–18	8–13	5–8	12	4–21	8–21	**–**
3.3	Total volume of collection trucks (m^3)	336	32	48	116	89	–	135	103	29	12	220	367	**1487**
3.4	Total weight capacity of collection trucks (ton)	198	21	31	75	58	64	79	67	19	8	139	239	**997**

(continued)

Table 10.4 (continued)

3	Truck capacity												
#	Item	JSC											
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
3.5	Daily collected quantities (ton)	235	36	84	60	85	66	37	110	36	7	128	289	**1062**
3.6	Daily amount of waste (t)/weight capacity of collection truck (t)	1.19	1.73	2.69	0.80	1.47	1.03	0.47	1.64	1.92	0.88	0.92	1.21	**1.06**

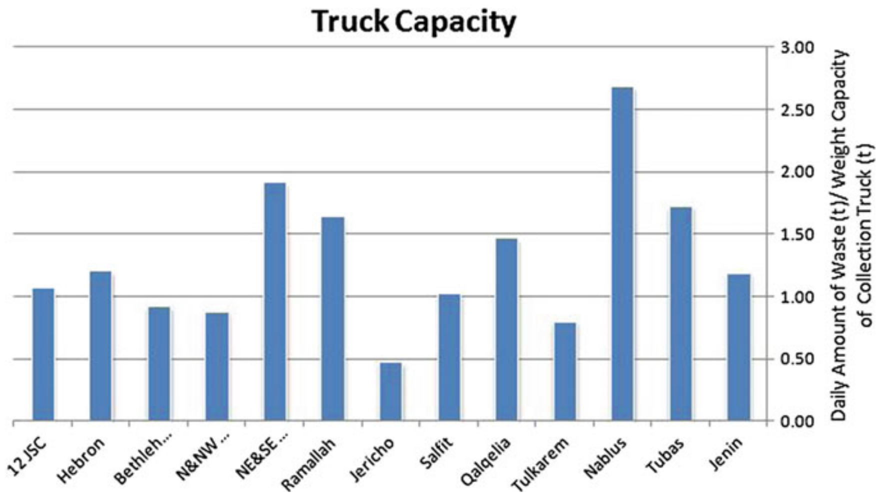

Fig. 10.3 Daily amount of waste (t)/weight capacity of collection truck (t)

10.2.4 Workers' Performance

The worker performance is measured by calculating the served population number and the collected waste per worker. The average served population per worker in the 12 JSCs is 3579, and the average daily collected waste per worker is 2.63 ton. According to the results shown in Table 10.5, the best workers' performance exists at Hebron JSC where each worker serves 7977 people and collect 4.73 ton of waste per day. The lowest workers' performance exists at Jericho JSC where each worker serves 2225 people and collects 1.54 ton of waste per day; this is because Jericho area is a wide and low dense area, and the transportation of waste takes a long time (Figs. 10.4 and 10.5) [12].

10.2.5 Transferred Quantities

There are 11 transfer stations in the West Bank 60% of the collected waste by the 12 JSCs (632.1 ton/day) is transferred to sanitary landfills through transfer stations, the minimum transferring distance is 25 km which exist in Hebron and NE + SE Jerusalem areas, and the maximum transferring distance is 80 km which exist in Qalqelia (Table 10.6 and Fig. 10.6) [8].

Table 10.5 Workers performance in the 12 JSC [8]

#	Workers performance													
	Item	JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
1	No. of collection workers “including drivers”	110	12	30	30	48	25	24	–	12	3	49	61	**404**
2	No. of served people per worker	2498	4777	4505	2500	2294	2800	2225	–	2774	2787	2892	7977	**3579**
3	Collected waste per worker (ton)	2.14	2.99	2.79	2.01	1.77	2.63	1.54	–	3.01	2.28	2.60	4.73	**2.63**

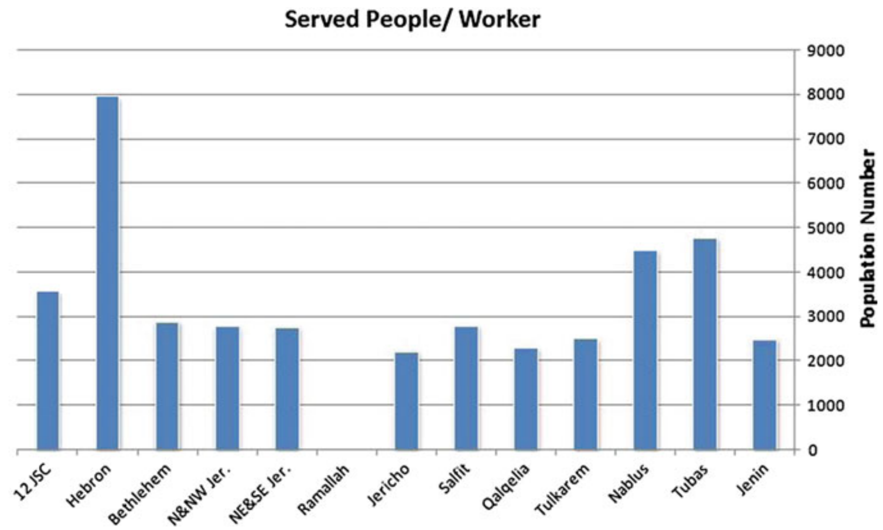

Fig. 10.4 Served people/worker in the 12 JSC areas

Fig. 10.5 Collected waste/worker in the 12 JSC areas

Table 10.6 Percentage of transferred quantities in the 12 JSC areas [8]

#	Transferred quantities													
	Item	JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
1	Quantity of transferred waste (t/d)	50	36	74	60	85	0	2.1	0	36	0	0	289	**632.1**
2	Daily collected quantities (ton)	235	36	84	60	85	66	37	0	36	7	128	289	**1062**
3	Percentage of transferred quantity (%)	21	100	88	100	100	0	6	0	100	0	0	100	**60**
4	Transferring Distance (Km)	35	35	40	35	80	0	40	0	25	0	0	25.35	–

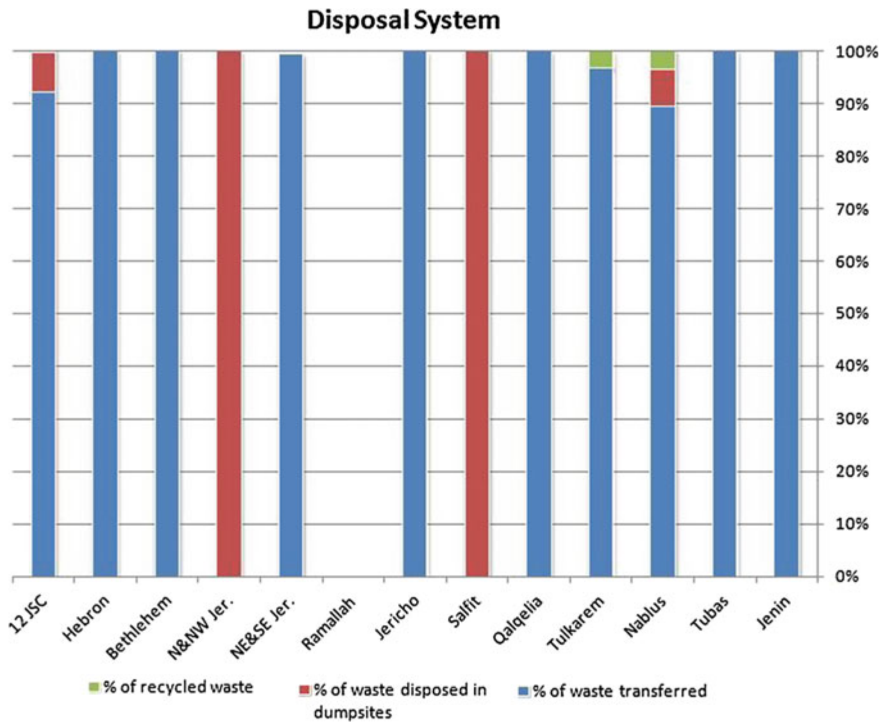

Fig. 10.6 Disposal system in the 12 JSC areas

10.2.6 Disposal System

92% of the collected waste by the 12 JSCs (979 t/d) are sent to sanitary landfills, 7% (79 t/d) are sent to random dumpsites, and only 1% (13 t/d) are recycled (see Table 10.7) [6].

10.2.7 SWM Cost

The average cost of SWM in the 12 JSC areas is 145 NIS/t. The maximum cost is at NE + SE Jerusalem JSC which is 248 NIS/t. This high cost is due to the high transferring and landfill fee compared to other JSCs. The minimum cost is at Salfit JSC which is 60 NIS/t where there is no transferring or landfilling cost; they send the waste to dumpsites. The average collection cost is 92 NIS/t, the maximum cost is at Jericho JSC, and the minimum cost is at Qalqelia JSC (see Table 10.8) (Figs. 10.7, 10.8, 10.9, and 10.10) [12].

Table 10.7 Disposal system in the 12 JSC areas [8]

#	Disposal system													
	Item	JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
	Daily collected quantities (ton)	235	36	84	60	85	66	37	0	36	7	128	289	**1062**
1 *Sanitary landfill*														
	Quantity (t/d)	235	36	75	58	85	0	37	0	36	0	128	289	**979**
	Percentage (%)	100	100	89	97	100	0	100	–	100	0	100	100	**92**
2 *Dumpsites*														
	Quantity (t/d)	0	0	6	0	0	66	0	0	0	7	0	0	**79**
	Percentage (%)	0	0	7	0	0	100	0	–	0	100	0	0	**7**
3 *Recycle, compost, etc.*														
	Quantity (t/d)	8	0	3	2	0	0	0	0	0	0	0	0	**13**
	Percentage (%)	3	0	4	3	0	0	0	–	0	0	0	0	**1**

Table 10.8 SWM cost [8]

#	Item	SWM cost/JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
1	Collection cost (NIS/t)	75	97	58	95	47.5	60	145	–	137	–	108	97	**92**
2	Transfer cost (NIS/t)	30	17	40.5	37	43	–	8	–	60	–	–	17.5	**32**
3	Landfilling cost (NIS/t)	30	30	27.5	33	33	–	19	–	50.5	–	30	30	**31**
4	Total cost (NIS/t)	135	144	118	165	124	60	174	–	248	–	138	145	**145**
5	Annual collection cost per inhabitant (NIS)	23.4	22.2	13.1	27.8	13.4	20.6	36.7	–	54.3	–	35.5	21.0	**27**
6	Fuel cost per ton of waste (NIS)	25.0	27.9	20.0	31.0	13.9	22.5	22.0	–	33.3	–	32.0	26.5	**25**

(continued)

Table 10.8 (continued)

#	Item	SWM cost/JSC												
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron	12 JSC
7	Labor cost per ton of waste (NIS)	34.0	36.8	24.8	36.0	30.6	30.0	56.0	–	56.7	–	39.5	13.9	**36**
8	Maintenance cost per ton of waste (NIS)	13.0	19.1	17.7	10.5	27.0	13.3	21.5	–	33.3	–	20.0	14.3	**19**

Note

[1]The total cost (NIS/t) considered the following point:

$ (USD)= 3.8 NIS

Nablus JSC: 12% of the collected waste is sent to dumpsite (no transferring cost or landfilling cost)

Jericho JSC: 6% of the collected waste is sent to Al Sairafi transfer station and cost 65 NIS/t for transferring and landfilling at Zahrat Al Finjan sanitary landfill

[0]There is no data at Ramallah JSC, where there was no service providing during 2016

[1]There is no data at N + NE Jerusalem JSC, where there some of the cost items are covered directly by the LGUs, and there is no available data

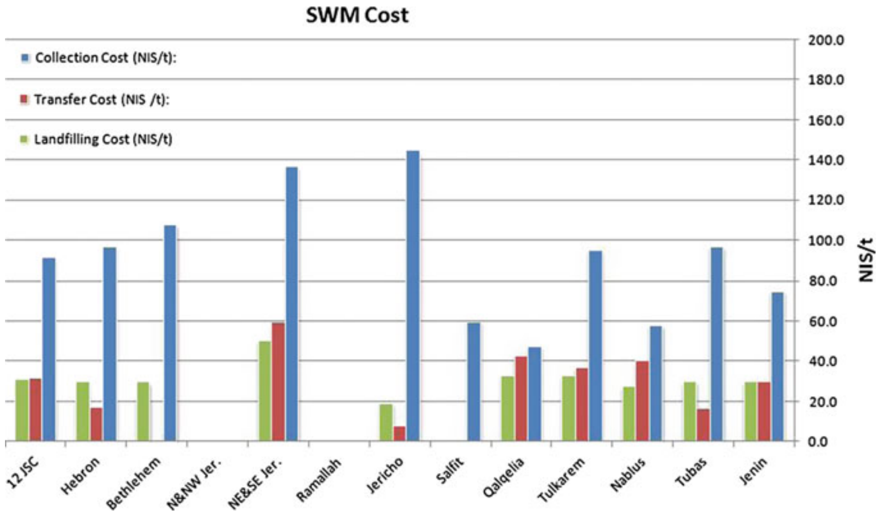

Fig. 10.7 SWM cost/collection, transferring and disposal cost

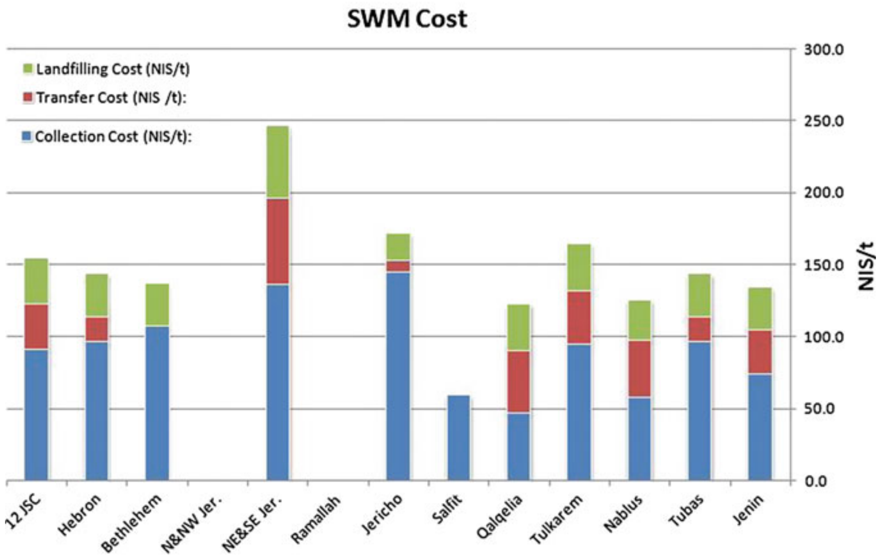

Fig. 10.8 SWM cost/total

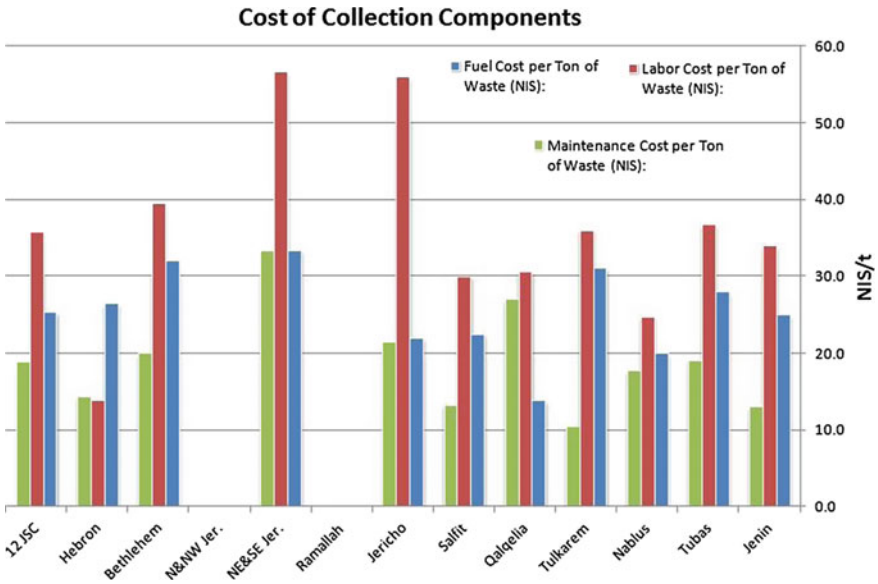

Fig. 10.9 Components of waste collection

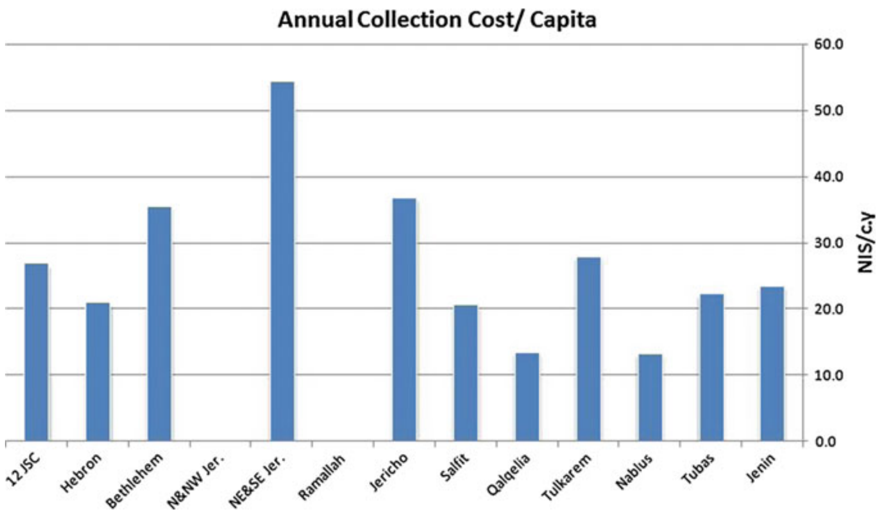

Fig. 10.10 Annual waste collection per capita

10.2.8 Tariff System and Fee Collection Data

The tariff system is different from one JSC to another; the tariff system in some of the JSC is based on the collected tons, some of them based on the population number and some of them based on the household number. At Jericho JSC, Jericho municipality pays a fixed fee for the JSC regardless of the amount of the collected waste or the number of the served population (see Table 10.9).

The applied tariff is more than the cost in all of the JSCs except at tubas JSC. In some cases, the cost recovery is less than 100% even when the tariff is higher than the cost (like Jenin JSC), and this is because the percentage of fee collection from some of the LGUs is less than 100%.

10.2.9 Institutional Aspect

All of the JSCs have basic plan, annual plan, and financial plan except Tulkarem JSC they don't have a financial plan. The JSCs whom don't have internal bylaw are Qalqelia JSC, NE + SE Jerusalem JSC, and N + NW Jerusalem JSC. There is a problem in many of the JSCs in conducting the annual GA meetings, according to the JSC Bylaw/2016, the minimum annual number of the GA meetings shall be two. At Hebron JSC, Tubas JSC, Nablus JSC, and Jenin JSC, no GA meetings were conducted during 2016. At Tulkarem JSC and Ramallah JSC, the conducted number of GA meetings was one during 2016 which less than the minimum number required by the JSC Bylaw/2016. Also, there is a problem in conducting the BD meetings, according to the JSC Bylaw/2016; the BD members shall meet at least once per month, which means that the minimum annual number of the BD meetings is 12. At Hebron JSC, Bethlehem JSC, Jericho JSC, Tulkarem JSC, and Tubas JSC, the conducted number of BD meetings was less than 12 (see Table 10.10) [8].

10.3 Solid Waste Management Capacity in 2022

10.3.1 Waste Collection Plan in 2022

The planned generation amount of wastes in 2022 (which is equal to the waste collection amount) is summarized in Table 10.11. The service population in 2016 is estimated based on the official projection of PCBS with adjustment of the actual condition. The unit generation rate of waste of JSCs at present is used for the rate in 2022.

Table 10.9 Tariff system [8]

Tariff system													
#	Item	JSC											
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron
1	Collection fee "from LGU to JSC"	170 NIS/t	133 NIS/t	125 NIS/t	133–173 NIS/ton	3.7 NIS/c.m	10 NIS/HH	Jericho City: L.S Villages: 22–32 NIS/HH	–	248 NIS/t	–	120 NIS/t	105 NIS/t
2	Total cost	135 NIS	144 NIS	118 NIS	165 NIS	2.9 NIS/c.m	1.7 NIS/c.m	174 NIS/t, 3.7 NIS/c.m	–	248 NIS/t	–	108 NIS/t	97 NIS/t
3	% of cost recovery (%)	82	91	92	98	100	NA	100	–	NA	–		93

Table 10.10 Institutional data [8]

9	Institutional data												
#	Item	JSC											
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho	Ramallah	NE&SE Jer.	N&NW Jer.	Bethlehem	Hebron
1	Existing of basic plan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Existing of annual plan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Existing of financial plan	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Existing of internal bylaw	Yes	Yes	Yes	Yes	Draft	Yes	Yes	Yes	No	No	Yes	Yes
5	Existing of organiza-tional chart	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	No. of manage-ment staff	15	2	8	6	6	4	11	5	4	2	6	10

(continued)

Table 10.10 (continued)

9	Institutional data												
7	Existing of employed ED	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Existing of employed accountant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	No. of board of directorate members	21	5	8	7	7	9	5	9	11	5	13	7
10	No of board of directorate annual meeting	12	6	12	7	12	12	4	12	12	20	6	0
11	No. of general assembly members	72	10	20	27	29	19	17	68	12	16	36	24
12	No of general assembly annual meeting	1	0	0	1	2	2	2	1	2	5	1–2	0

Table 10.11 Waste collection plan in 2022 [8]

	Target population in 2022	Severed population in 2022	Planned waste generation amount (t/d) in 2022	Unit generation rate (kg/day/capita) in 2022
N&NW Jerusalem	58,374	58,374	63	1.08
NE&SEn Jerusalem	204,283	203,384	133	0.66
Qalqiliya	126,630	126,630	126	0.99
Nablus[a]	362,137	253,496	199	0.70
Tubas	70,989	70,989	48	0.68
Tulkarem	170,563	170,563	97	0.76
Salfit	85,738	85,738	80	0.93
Jericho	54,344	54,344	47	0.86
Bethlehem	237,641	175,357	174	0.99
Hebron	846,396	580,039	418	0.72
Jenin	381,480	343,603	297	0.86
Ramallah[a]1	393,817	157,527	98	0.62
South Gaza	795,534	419,792	205	0.49
North Gaza[a]	1,117,236	279,309	275	0.98
Total	4,905,162	2,979,145	2260	0.81

10.3.2 Required Capacity for Vehicles in 2022

The target year of the calculation for vehicle necessity is set at the year 2022 (the target year of the national strategy). Old and deteriorated vehicles are replaced to new ones (100% replacement for the vehicles manufactured year before 2010, 50% between 2011 and 2015, and 0% after 2016, which is equivalent to 0, 50, and 100% of effective rate, respectively). It is expected that there would be no or few additional drivers or workers for the replaced vehicles and that O/M cost would decrease (see Table 10.12).

10.4 Summary of National Strategy for Solid Waste in Palestine

The "National strategy for Solid Waste Management in Palestine 2017–2022" here in after referred to as NSSWM is the second strategy, at the national level, for SW in Palestine. Thus, it constitutes the framework for all decisions, programs, activities, and medium-term investment plans, aiming at developing the SW sector in Palestine.

Table 10.12 Required capacity for vehicles in 2022 [8]

Table 3.1 Required capacity for vehicles in 2022

Items	Tulkarem	Salfit	Jericho	Bethlehem	Hebron	Jenin	Ramallah	North Gaza	South Gaza	N&Nw Jerusalem	NE&SE Jerusalem	Qalqiliya	Nablus	Tubas	Total
Planned collection amount (t/d) in 2022	97	80	47	174	418	297	409	205	57	63	133	126	177	48	2,332
Existing vehicle (t/d) in 2022	40	20	25	40	176	9	72	71	0	17	14	15	11	6	516
New vehicle (shortage capacity) in 2022	57	60	22	134	242	288	337	134	57	46	119	111	166	42	1812
Existing vehicles															
Compactor	40	20	23	38	16	9	72	0	71	17	14	15	11	6	502
Dump truck	0	0	2	2	10	0	0	0	0	0	0	0	0	0	14
Tipper Crane Truck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(continued)

Table 10.12 (continued)

Table 3.1 Required capacity for vehicles in 2022															
Items	Tulkarem	Salfit	Jericho	Bethlehem	Hebron	Jenin	Ramallah	North Gaza	South Gaza	N&Nw Jerusalem	NE&SE Jerusalem	Qalqiliya	Nablus	Tubas	Total
Grapple truck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub total	40	20	25	40	176	9	72	0	71	17	14	15	11	6	516
New vehicles															
Large com-pactor type (21 m^3)	10	0	0	0	40	60	0	0	0	0	20	20	40	0	190
Medium com-pactor type(13 m^3)	52	38	12	114	76	171	247	57	57	18	39	57	104	12	1054
Small com-pactor type (8 m^3)	0	0	12	0	0	48	0	0	0	24	40	36	8	24	192
Sub-total	62	38	24	114	116	279	247	57	57	42	99	113	152	36	1436
Total	102	58	49	154	292	288	319	57	128	59	131	128	163	42	1952

The preparation process for setting this strategy started with revising and updating the previous strategy for the years 2010–2014, and considering all the different aspects which the participatory approach working in this sector in the process of all relevant institutions and ministries working in this sector in the process of revision, this was done by a technical team representing these parties, entrusted by the National Committee in-charge of developing the national strategy by virtue of the Cabinet decision.

Following are the strategic objectives and the sectoral policies by the NSSWM, as explained in detail in Sect. 10.4 **of the strategy document**.

Strategic Objective One: *A Modern and effective legislative and organizational framework for SWM*.
Policy (1): Development and update of the legislative framework supporting integrated SWM.
Policy (2): Strengthening the organizational frame of national institutions and supporting their complementary roles in SWM.
Strategic Objective Two: *Strong institutions capable of performing its duties*.
Policy (3): Enhancing institutional capacity building and expertise in SWM.
Strategic Objective Three: Effective and environmentally safe management of SW services.
Policy (4): Developing the current management systems for SW collection and transport, in order to improve the quality and of services and its availability to all citizens.
Policy (5): Safe and efficient disposal of SW in regional sanitary landfills servicing all communities or using proper advanced technological methods.
Policy (6): Encouraging policies and methods of SW reduction, recycling, reusing, and regeneration before final disposal at regional sanitary landfills.
Policy (7): Prohibiting the use of random dumpsites and closing or rehabilitating the existing sites gradually to limit their negative impact on health and environment.
Policy (8): Minimize the amounts of greenhouse gases (GHG) emitted as a result of SW activities to reduce its impact on climate change.
Strategic Objective Four: Attaining financial sustainability and efficient SWM services and activities.
Policy (9): Reducing the cost for collection and transport of SW.
Policy (10): Achieving cost recovery and self-financing for SWM operating costs.
Strategic Objective Five: Principles and mechanisms suitable for managing medical hazardous and special wastes.
Policy (11): Establishing appropriate and unified inventory and tracking systems for hazardous waste, and availability of necessary information, setting a sound and safe systems (separation, collection, transfer, and disposal processes) to manage it.
Policy (12): Treatment of medical waste before its final disposal, according to the "polluter pays" principle, to limit its negative health and environmental impacts.
Policy (13): Management of special waste in manner that ensure protection of health and environment.
Strategic Objective Six: Increasing the participation of the private sector in SWM

Policy (14): Raising awareness and setting foundations and necessary measurements to create and enabling investment environment that encourages the private sector to participate and investment.

Strategic Objective Seven: Amore participating and aware community.

Policy (15): Deeping community environmental and institutional awareness and knowledge of SW issues and impact.

Policy (16): Raising student's environmental awareness and developing their skills and orientations in the aspects of SW reduction and recycling.

Policy (17): Providing students with equipment and tools that will enable them to acquire knowledge and skills required for SW recycling (e.g., recycling tools, composter).

Strategic Objective Eight: Eight Effective information and monitoring systems

Policy (18): Establishing a unified national database for SW.

Policy (19): Developing and enhancing administrative, financial and environmental monitoring system.

10.5 Conclusion and Recommendations

Today in the year 2018, a clear picture of the municipal solid waste as part of the solid waste sector is exposed in one document for the first time in Palestine. This chapter can be considered as a reference for all interested parties, where it provides all needed information about the future planning for SWM in MENA region and the related data including the institutional issues, vehicles, workers, generated and collected quantities, the designated landfills, etc.

This chapter will enable the planners and decision makers to develop their plans and make decisions depending on real facts. On the other hand, it also facilitates the evaluation processes by the related stakeholders including the comparisons among the different JSCs itself especially the efficiency of the service provision considering all the dependent factors.

In the future and depending on the new activities that could be developed by the service providers or the research institutions, the composition of the municipal solid waste could be included in this data book.

Finally, we would like to recommend the different stakeholders to do the following:

1. The JSC Department should update and publish the data book every two years.
2. The JSCs should publish their data for the public through the Web site or social media, and they should update the data every year.

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Chapter 11
Waste Management in Lebanon—Tripoli Case Study

Jalal Halwani, Bouchra Halwani, Hilmiya Amine and Mohammad Bachir Kabbara

Abstract Lebanon appears as the bad student in solid waste management (SWM) in Middle East Region, varying techniques of SWM is currently practiced in different parts of the country, a comprehensive approach to SWM in Lebanon is still now virtually absent, slow burning and uncontrolled dumping on hillsides and seashores are still common methods practiced for solid waste disposal. Except SWM in the Greater Beirut Area (GBA), solid waste continues to be managed in a manner that is not protective of either human health and/or the environment. Even in the extended GBA, serious questions are raised about the policy commitments to promoting and eventually requiring sustainable and environmentally friendly SWM practices. Tripoli (second city and capital of North Lebanon) is facing an environmental disaster; the actual landfill is over saturated and can collapse in any moment causing dangerous damage in the environment. Landfill must be closed in 2012, but continue to dump waste in reason of lack an alternative new site. Certainly, the trend will be changing and there will a great deal of effort to develop integrated SWM systems for most areas in Lebanon, particularly large urban areas. These efforts center on the construction of controlled sanitary landfills in combination with sorting, recycling, and composting facilities or waste-to-energy systems (incinerator or biological anaerobic plant).

Keywords Lebanon · Solid waste management · Landfill · Tripoli

11.1 Introduction

Lebanon population are about 5 million people that produce around 2 thousand tons of municipal solid waste (MSW) per year, while the composition of the wastes is in majority organic (near 55%). However, the organic matter is varying from urban to rural areas and from summer to winter as well [1]. Paper/cardboards and plastics constitute a significant proportion, with glass and metal contributing largely too, high moisture content is also prevalent in wastes, often exceeding 65%. It is considered

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Table 11.1 Municipal solid waste generation by Mohafazat

Mohafazat	Tons/day	% of generation
Mount Lebanon	2250	40.2
Beirut	600	10.7
North Lebanon	1000	17.9
Bekaa	750	13.4
Nabatiyeh	350	6.3
South Lebanon and Nabatiyeh	650	11.6
Total	5600	100.0

Source SWEEP-NET [1], Country Report on the Solid Waste Management in Lebanon, giz

that the MSW generation per capita varies from around 0.7 kg/p/d in rural areas to around 0.85–1.1 kg/p/d in urban areas, with a national weighted average estimated at around 0.95 kg/p/d [2]. The foreseen increase in waste generation is estimated at an average of 1.65% across the country; this growth is however highly unevenly distributed.

Waste disposal is particularly difficult in Lebanon because of its rugged terrain and limited surface area. Lebanon currently produces about 5600 tons of municipal solid waste (MSW) per day (see Table 11.1), composed of about 52.5% organic matter; 36.5% paper, cardboard, plastic, metal and glass; and 11% inert and other materials [1]. Waste is currently disposed of as follows: about 50% in uncontrolled dumpsites (about 940 dumpsites); about 35% in sanitary landfills (Bourj Hammoud, Costa Brava, and Zahle); and the remaining waste (about 15%) undergo material recovery, sorted into recyclable or reusable materials (paper and cardboard, plastic, metal, glass, etc.) or converted into organic soil compost in approximately 50 facilities across the Lebanese territories [2]. Despite its importance in reducing landfilling, energy recovery is practically not carried out in these existing facilities, except Saida and Naameh (closed in 2017).

In addition to MSW, Lebanon produces about 50,000 tons of hazardous solid waste each year: hazardous industrial chemical waste; electronic waste; expired solid drugs and materials; healthcare waste (hazardous non-infectious waste, waste requiring special management, hazardous infectious waste, etc.); used oil; used tires; used batteries; persistent organic pollutants from the energy sector or other sectors; various types of sludge, etc. [3]. Also, there are other wastes such as solid waste from the olive oil industry [4], slaughterhouse waste, construction and demolition waste, and bulky refuse/waste.

Environmentally sound treatment of hazardous solid waste and other waste is also non-existent, as most are disposed in a haphazard manner, with the exception of a portion of healthcare hazardous infectious waste [5], that is treated in accordance with the provisions of Decree 13389/2004, and some types of hazardous waste that are exported in accordance with the provisions of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Law 389/1994), [6].

Over the past 20 years, despite considerable progress in shaping its legal and institutional framework and providing substantial public funds for financing its infrastructure after the war, Lebanon is still at an early stage of its transition to environmental sustainability [7]. Contrary to the municipal solid waste collection services, whose improvements were both effective and equitable over the years, the solid waste treatment and disposal subsector continue to face stern challenges. Lebanon experienced a string of SMW plans, such as transforming waste-to-energy (WTE) in 2010 in Saida Plant (anaerobic digestion), open dumps are getting out of control; most old major dumps were not closed down properly or rehabilitated [8].

The institutional framework is quasi-absent, and cost recovery for waste disposal and treatment is zero [9]. SWM services are provided by the private sector through regional solid waste contracts which increased regional monopoly powers and reduced competition and therefore efficiency [10].

On September 24, 2018, the Lebanese Parliament endorsed the draft SWM law which has stirred controversy inside the parliament and was faced with objection from several MPs.

11.2 Tripoli Case Study

11.2.1 Solid Waste Management in Tripoli

Tripoli, the second capital of Lebanon, like many cities, suffers from the absence of the proper SWM. Proper management of solid waste relies on the proper collection and disposal of municipal solid wastes (MSW) in the landfill. Collecting MSW is the mission of a private company LAVAJET when BATCO (sister company) is in charge of the landfill operation [11]. Households do not practice formal waste separation. The collection contractor is supervised by the Council for Development and Reconstruction (CDR) on behalf of the Union of Al-Fayhaa Municipalities, UFA (Tripoli, Mina, Baddawi, and Kalamoun).

Tripoli landfill is situated along the coastline, north to the Port of Tripoli and adjacent to the Abou Ali River estuary and covers an area of approximately 60,000 m^2 (see Fig. 11.1). It started to receive waste in 1980 and in the year 2000 it was converted into a semi-controlled dump with the integration of a gas collection system and containment wall. The dump currently receives an average of 450 tons/day. It should be closed end of 2012 but unfortunately it is still receiving waste till now, it becomes a mountain fully saturated which can fall apart at any time causing an ecological disaster that Lebanon has never known [12].

For over 20 years and up till 1999, the site was being used as a “boundary-less” savage dumpsite catering to Tripoli and its surroundings. Needless to say, this situ-

Fig. 11.1 Tripoli Landfill

ation was causing an environmental catastrophe zone in terms of pollution, vectors, odor, fires, etc. In 1997, and as an initial step to solving this prevailing problem, a peripheral seaside wall was constructed to stop the expansion of the dumpsite into the Mediterranean Sea. And in 1999, UFA initiated a project to rehabilitate the site and to operate it as a controlled landfill. The Council of Development and Construction (CDR) contracted a private contractor to improve waste disposal practices and manage the controlled dump, by retrofitting it with gas extraction wells and flaring units [13].

The operation of the Tripoli Landfill includes control of incoming wastes, proper waste placement, and compaction, application of daily cover, biogas flaring and limited leachate control (both stopped in 2013), this operation has alleviated the once prevailing adverse environmental conditions. The Tripoli Landfill receives wastes from Tripoli, El-Mina, El-Bedawi, El-Qalamon cities, and north Palestinian refugee's camps at an average rate of around 450 tons/day. The piled trash had reached its maximum capacity in 1992, and that it was not possible to accept more waste, but unfortunately, up until it continues to operate with a risk of thousands of tons of trash could be to spread into the sea (see Fig. 11.2), causing an ecological catastrophe in the Mediterranean [14].

Some scavengers are allowed in the landfill by the UFA; they enter and collect their desired recyclable material from the receiving area immediately before the waste is spread in specific areas of the dump. Collected recyclables include plastic, iron, metals, and previously cardboard. Scavengers work quickly and collect what

Fig. 11.2 Sea view of Tripoli Landfill

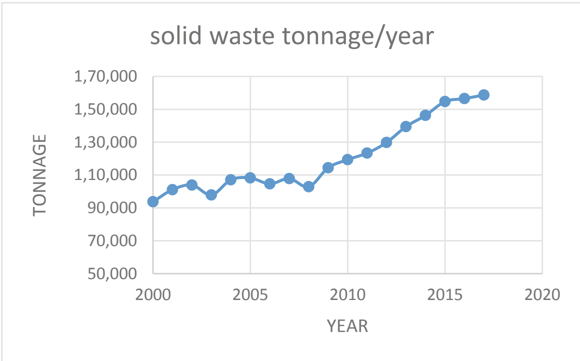
Fig. 11.3 Aerial view of Tripoli Landfill

is visible to them while heavy machinery is maneuvering around. This means that a very low percentage of incoming waste is sorted out for marketing.

For the moment, the estimated volume of waste in place is more 1.1 Million m^3 based on a review of the topographic maps, spread over a total area of 60,000 m^2. The highest point of the dumpsite is around 45 m (see Fig. 11.3), the annual volume of waste landfilled is shown in Table 11.2 [15].

Table 11.2 Disposed waste quantities for the period 2000–2017

Year	(Tones/year)
2000	93,749.74
2001	101,082.16
2002	103,886.90
2003	97,893.10
2004	107,101.96
2005	108,221.18
2006	104,631.48
2007	107,820.72
2008	102,866.54
2009	114,419.28
2010	119,371.02
2011	123,342.02
2012	129,818.09
2013	139,496.32
2014	146,270.15
2015	154,700.04
2016	156,510.00
2017	158,720.00



11.2.2 Landfill Operations

The landfill is currently operated according to the following procedure:

11.2.2.1 Inspection

Contents of the incoming refuse collection vehicles (RCV) are visually inspected to check their compliance with permissible wastes. Approved vehicles are allowed to proceed for weighing.

11.2.2.2 Receipt at Weighbridge

The weighbridge transaction includes the following:

- Identification of the RCV and the transporter;
- Origin of the MSW;
- Type of the MSW;
- Entry date and time;
- Tare weight of the RCV and net weight of MSW.

11.2.2.3 Landfilling

RCV proceed to the landfill area utilized according to the waste filling program. Contents are discharged in the designated area, spread and compacted in layers of approximately 50 cm then covered with at least 15 cm of inert soil material. Permanent and temporary access road is provided for the ability to use for transportation of the solid waste material for the required active area. After that, the transporter comes back to the weighbridge to withdraw the certification of the material disposed of.

11.2.2.4 Leachate Collection and Disposal

Leachate collection is drained into pits and was partially treated during 4 years (2009–2013) in a treatment plant. The leachate generated by the Tripoli Landfill activity was subject to a recirculation process consisting of spraying and evaporating the leachate on the compacted solid waste and recollecting the leachate through a peripheral network beneath the solid waste. However, this process has been jeopardized by the construction of the peripheral trenches as well as by the increasing height of the solid waste, where the related equipment (pumps, etc.) could not sustain such variations.

As for the leachate treatment process [16], it consists of a biological treatment process that includes (see Fig. 11.4) an aerobic digester with nitrification and anoxic denitrification; clarification; chlorination; and filtration (sand and carbon filter). Unfortunately, this treatment plant did not reach its desired treatment level as originally planned where the entering rainwater and the increasing volume and height of solid waste overwhelmed the design capacity of the plant (36 m^3/day). All efforts were taken to improve the treatment level of the plant gone without success. Therefore, part of the leachate is recirculated in the landfill itself or is discharged into the river discharging in the sea (see Fig. 11.5).

11.2.2.5 Gas Collection

Different vertical landfill gas (LFG) wells have realized across the site and connected them to regulation stations connected to the flare (see Fig. 11.6). A large capacity LFG flare (1100 m^3/h) has been procured and installed in 2009 by the contractor to replace the initially installed LFG flare (500 m^3/h) in the year 2001 to account for the increased LFG production and collection in view of the landfill closure and the installation of the final cover, which was initially planned for the end of year 2009.

The system was stopped in 2013 because the LFG wells need to be elevated vertically as waste is dumped vertically. This operation necessitates putting the wells that are being elevated off-line to avoid the air suction in the system with additional piping and connections to the reinstalled regulating stations [17].

Fig. 11.4 Leachate treatment unit in Tripoli Landfill

The failures that occurred in the outer face of the earth reinforced wall imposed some actions to avoid jeopardizing its stability, which led to increasing the level of oxygen in the extracted LFG by the flare suction unit [18].

It should be noted that the Tripoli landfill gas flare couldn't be duly and properly operated in the existing conditions that prevail in the landfill, namely the increasing height of the solid waste (more than 32 m), the peripheral trench excavated to alleviate the solid waste active pressure on the peripheral wall, the continuous operation preventing the installation of the final cover, etc. Indeed, the extracted gas sent to the flare should be relatively pure in order to ensure proper operation of the equipment, thus, in the existing conditions, the extracted gas is mixed with air due to the trenching that was done for stability purpose.

The gas flare can be duly and properly operated continuously once the peripheral trench is backfilled, gas wells upgraded to allow for the actual increasing height that the landfill has reached, landfill closure date is known, and the final cover is placed.

For the moment, the biogas released is confined in the landfill, and it is considered as a time bomb and could be at the source of an accidental big fire with the bad consequences to the health and the environment.

Fig. 11.5 Leachate discharged to the Abou Ali River

11.2.2.6 Peripheral Wall

The waste mountain stretches 45 m high from the surrounding terrain. It is an enduring eyesore and health threat to residents and tourists. The environmental repercussions are severe; occupational hazards related to incoming uncontrolled waste, possible recurring waste slides into the Mediterranean Sea with the threaten to Natural Marine Reserve of Palm Island located at 10 km.

In order to avoid the expansion of the dumpsite into the Mediterranean Sea, a peripheral seaside wall was constructed in 1999. It consists of concrete blocks, geotextile, and geogrid materials (see Fig. 11.7); the backfill is composed of sandy gravel and clay soil. The peripheral wall of the landfill is monitored via topographic surveys, which are conducted on a monthly basis using 11 stations about the middle of the peripheral road at the top of the wall and 10 stations on the concrete hollow blocks forming the facing of the wall.

A structural failure in the peripheral wall occurred many times since 2011, where parts of the reinforced earth wall collapsed along due to sliding of the waste mass. Whereas other parts within this section remain unstable, although the blocks which constitute the facing of the wall and some of the fill have collapsed, no shear failure is observed in the reinforced fill massif. Preventive measures by repairing some portions of the wall in particularly adjacent to the river have regularly undertaken

Fig. 11.6 Gas collection network in Tripoli Landfill

to avoid any potential sudden burst. Note that the activities adjacent to the landfill, including land reclamation (north of the site: future new Special Economic Zone) and stone crushing and vibration screening activities (south of the site: private illegal exploitation), are expected to have contributed in the collapse of the waste mass.

In April 2018, two sections of the peripheral wall collapsed in separate incidents warned of an impending environmental disaster, fortunately no trash had fallen from the dump as a result of the cracks, only some bricks have fallen from the site. In the picture (see Fig. 11.8), we can show bricks missing from the wall, but the waste appeared compact and contained between layers of permeable liner. To avoid an environmental catastrophe, an additional wall was built to reinforce the side that partially collapsed (see Fig. 11.9).

The landfill has to be closed in the year 2010, for saturation conditions, but it continues to operate because of the non-finding alternative site, despite the existing danger (breakdown, collapses, fire, …), the discharge of leachate to the sea or the Abou Ali river, and the non-extracted and incinerated biogas generated [19]. The extended date of closure was due on the end of the year 2012, but the landfill is still operational until today.

Fig. 11.7 Part of the peripheral wall in Tripoli Landfill

11.2.3 Sorting and Composting Plant

A sorting and composting plant was built by the Office of the Minister of State for Administrative Reform (OMSAR) with the financial support from the European Union near the dumpsite area for a capacity 420 tons/day. But few weeks the plant started, the Union of Al-Fayhaa Municipalities (UFM) stopped him for the residents' complaints about its foul odor in the city, the weak recycled percentage (less than 5%) and the refuse of agriculture to use the compost for its bad quality (see Fig. 11.10).

After site inspection, it was clear that troubleshooting in the composting process and the sorting line were found and particularly in the biofilter and the maturation phase of compost.

For the moment, OMSAR and UFA work together to find a solution to solve this problem by introducing technical modifications to the facilities.

Currently, incoming waste undergoes no sorting whatsoever, the only form of sorting is done by the scavengers who are allowed, by authorization from the UFA, to enter the site and collect their desired recyclable material from the receiving area immediately before the waste is spread in specific areas of the dump.

Collected recyclables include plastic, iron, metals, and previously cardboard. Scavengers work quickly and collect what is visible to them while heavy machinery

Fig. 11.8 A partial collapse in the peripheral wall

is maneuvering around. This means that a very low percentage of incoming waste is sorted out for marketing.

11.2.4 New Maritime Sanitary Landfill

In the absence of the alternative sustainable solution for the management of solid wastes in Tripoli, and in reason of the dangerous situation of the actual landfill, the Lebanese government has decided the extension into a new temporary landfill located just in front of the actual landfill by reclaiming 60,000 m^2 (see Fig. 11.11). The new landfill which contains three cells and designed for 3 years must be operational at the beginning of 2019 (see Fig. 11.12). After that, the actual landfill must be closed, and its rehabilitation start.

This new reclaim sanitary landfill is the third site decided by the government after the Bourj Hammoud (North Beirut) and Costa Brava (South Beirut) sites.

Fig. 11.9 Additional protection built in front of the collapsed peripheral wall

11.3 Future Management Policy of Solid Waste

Uncontrolled dumping and improper waste handling cause a variety of problems, such as contaminating water, attracting insects and rodents, and increasing flooding due to blocked drainage canals. Also, it may result in safety hazards from fires or explosions. Improper waste management also increases greenhouse gas emissions, which contribute to climate change [20].

Therefore, Lebanon should adopt an efficient solid waste management system, based on preventing waste, recycling, composting, and finally disposing of the remainder. Waste prevention strategies include using less packaging, designing products to last longer, and reusing products and materials (such as stuffing used textiles into mattresses).

Recycling involves collecting, reprocessing, and/or recovering certain waste materials (metals, glass, papers, and plastic) to make new materials or products. As organic materials cannot be recycled, and as they are rich in nutrients, they can be converted into soil additives in a process called composting. However, the process of recycling and composting is heavily dependent on separation at source, whereby households should divide their wastes into different kinds, before being collected.

Finally, waste that can be neither prevented nor recycled or composted can be placed in a properly managed landfill to produce energy. These wastes undergo pro-

Fig. 11.10 None conform compost produced in Tripoli composting facility with leachate in open air

Fig. 11.11 Location of the new temporary landfill in Tripoli

Fig. 11.12 Reclaim to build a new temporary sanitary landfill in Tripoli

cedures which include combustion, gasification, pyrolization, anaerobic digestion, and landfill gas recovery to produce energy, what is known as waste-to-energy (WTE) process.

Finally, a roadmap for Lebanon to treat the waste may include the following. First, the citizens should be encouraged to participate in waste management by splitting their wastes into inorganic (glass, plastic, paper, textile, electronics), and organic. Another process of separation should occur after collection, to ensure appropriate segregation of domestic wastes. The recyclable refuse is then sent to a recycling plant, and the organic waste gets composted. Finally, the remnants get disposed of in sanitary landfills, where methane gas could be recovered and used to produce energy. Considering the implementation of such a process, Lebanon could be capable of transforming its waste from a burden on the government to a source of revenue, originating from the sale of recyclable materials and power generation.

11.4 Conclusions

In Lebanon, there are many difficulties to apply a good solid waste management practices some of them are:

- Increase in the population,
- Migration of the population from rural to urban areas,
- No precise studies are made on the right technologies,
- No legal framework and poor law enforcement,
- Contradiction in policies,
- No serious actions to implement incentives,
- No solo administration is dealing with this file,
- No financial act to recover the cost.

That's why Lebanon still remains in the labyrinth of anarchy. The government should take a decision for SWM with the techniques that should be considered regarding the appropriate sites for those techniques and the same time decide funding and cost recovery for them.

11.5 Recommendations

In Lebanon, solid waste management remains an environmental major problem, practices currently in use are decided at the last day and are put in front of the fait accompli and whatever the cost that may arise and the impact on health and the environment.

In the absence of a sustainable solid waste management policy, the consequences of these practices will be disastrous for the future of country. Public authorities must take into consideration the fact that the image of Lebanon is increasingly downgraded and the protection of the environment is no longer the priority for the country.

An extensive awareness-raising program on good practices in solid waste management for all citizens is needed, it is urgent to put in place preventive measures that consist in adopting eco-responsible behaviors and attitudes that make it possible to put in place sorting, selective collection, and recovery of wastes.

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Chapter 12
Reducing Methane Emissions from Municipal Solid Waste Landfills by Using Mechanical, Biological Treatment (Case Study Wady Alhaddeh (MBT) Plant, in Tartous)

Haytham Shahin

Abstract In developing countries including Syria, the solid waste sector contributes to the emission of greenhouse gases, mainly methane, due to the lack of methods of integrated management of solid waste in these countries. The objective of this research is to study the feasibility and effectiveness of mechanical, biological treatment of municipal solid waste in a way to reduce methane gas emissions compared to the indiscriminate dumping of municipal solid waste. To reach this goal, the formula contained in the guidelines of the International Panel on Climate Change (IPCC) is adopted for accounting the emissions of methane from the municipal solid waste sector in Tartous–Syria. The study is realized from 2010 until 2015 in the case of landfilling of municipal solid waste generated by the province in random landfills. To compare the account is an assumption that the same amount of municipal solid waste generated by the province during the years from 2010 to 2015 has been treated in accordance with the mechanical, biological treatment method. It also calculated the amount of methane emitted from municipal solid waste entering the integrated waste treatment center in the Province of Tartous within one year from the beginning of June 2014 until the end of May 2015, using mechanical, biological treatment method. This study concluded that the mechanical, biological treatment for municipal solid waste significantly reduces the amount of methane emissions from solid waste sector compared to the landfilling, where the percentage of reduction in the emission of methane is about 93%.

Keywords Municipal solid waste · Mechanical, biological treatment · Greenhouse gas · Methane gas

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12.1 Introduction

Due to the global hazardous phenomena result from global warming, there has been a dire need to find solutions for the environmental problems such as emission of greenhouse gases of CO_2, CH_4, N_2O, SF_6, PFC, and HFC [1, 2]. Under the national greenhouse gas agreements, all countries are required to submit annual reports on their GHG emissions and to adopt the appropriate mitigating techniques and procedures. It is well known in developing countries that the sector of wastes contributes to GHG emissions. The solid waste contains mostly organic material of 60% [1], which can be converted into landfill gases in the presence of aerobic bacteria. CH_4 is one of the most serious emitted gases. Methane causes 25 times more warming compared to carbon dioxide [3].

As for solid waste sector in developing countries including Syria, mechanical, biological treatment (MBT) has been considered the appropriate method for reducing greenhouse gas emission basically methane due to the fact that most of the mixed wastes are not segregated at their source, i.e., they need mechanical treatment to be sorted in purpose of facilitating the recycling process. A large amount of municipal waste represents organic fraction so that biological treatment is the most suitable method to be utilized for converting wastes into useful fertilizer and biogas after that [1, 4].

In recent years, several studies and research have concentrated on the process of mechanical and biological treatment as a solution for reducing the emission of greenhouse gasses particularly methane [5–7]. Thailand has two dominant methods for open dumping and landfill waste disposal in 2009 that were compared to the method of mechanical and biological treatment. It was statistically found that using mechanical biological treatment (MBT), emissions of greenhouse gasses including methane reached 161 kg CO_2-eq/ton, while GHG emissions from open dumps and landfills (without gas recovery) were 448 kg CO_2-eq/tons and 925 kg of CO_2-eq/tons, respectively [8]. In the UK, a study was conducted on biological treatment of organic wastes to be transformed to fertilizer instead of dumping has revealed that emission reduction rate increased to reach 74%. Methane reduction rate is related to the duration of biological treatment. In Milano, MBT facility reduced the potential anaerobic generation of methane gas to 56% after 4 weeks of treatment and to 79% after 12 weeks [9], while the reduction rate in Italy reached 67% after 8 weeks and 83% after 15 weeks [10].

Integrated center for solid waste treatment in Tartous Governorate (Wadi Elhadi) adopts mechanical and biological treatment (MBT) of wastes and conversion of organic matter into fertilizer. Figure 12.1 shows a scheme for the steps of waste treatment in the plant [11].

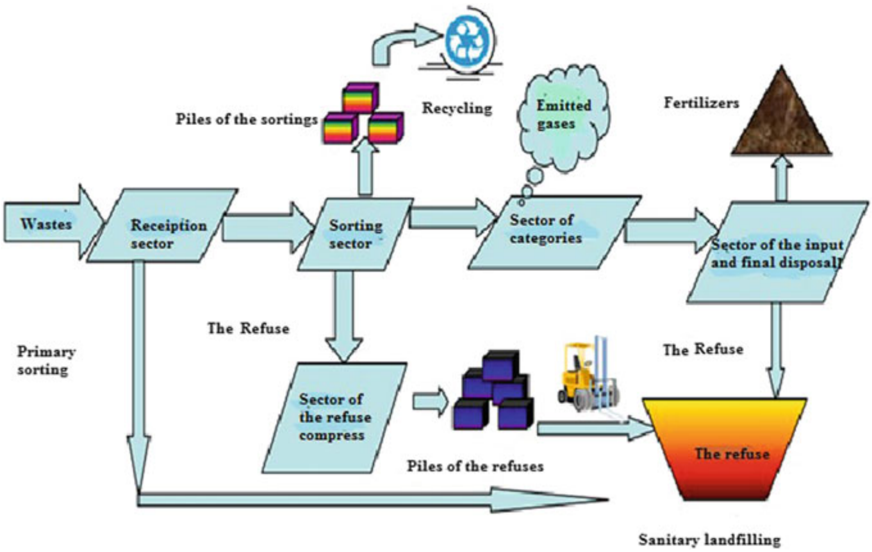

Fig. 12.1 Scheme for the steps of waste treatment in the plant

12.1.1 The Importance of the Study

Since solid waste decomposition is a source of the emission of GHG including methane which essentially contributes to the aggravated global warming, it is urgently required to treat solid wastes mechanically and biologically in order to mitigate the emission of GHGs, particularly in developing countries—in case no sorting of solid wastes and gas recovery are available. This study will achieve comparison between the methane content released from Tartous municipal landfills of solid wastes, which were not subjected to pretreatment, and that of mechanically and biologically treated wastes in the integrated center for solid wastes at Wadi Elhadi plant.

12.1.2 The Objects of the Study

1. Developing a database that includes the composition and characteristics of municipal solid wastes in Tartous.
2. Determination the content of methane result from MBT of municipal solid wastes at Wadi Elhadi as well as that of landfill wastes without pretreatment and landfill gas recovery.
3. Comparison-based determination of reduction rate of emission of methane.

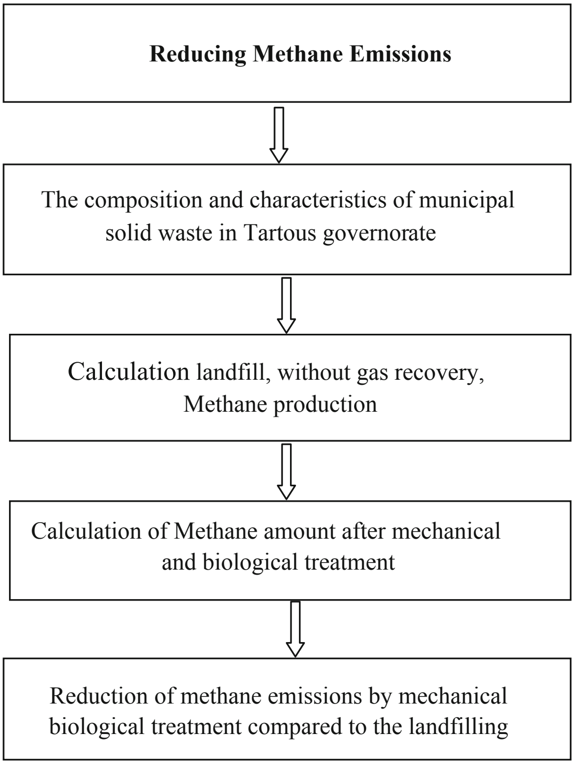

Fig. 12.2 Flowchart for the methodology

12.2 Materials and Methods

All calculations related to the determination of the methane content result from MBT of municipal solid wastes at Wadi Elhadi as well as that of landfill wastes, without pretreatment and landfill gas recovery, were done using equations mentioned in the IPCC guidelines [12]. Figure 12.2 shows the flowchart for the methodology.

Methane emission from solid wastes landfill was evaluated according to the following equation from [13]

$$CH_4\ \text{Emissions} = \left(\text{MSW}_T * \text{MSW}_F * \text{MCF} * \text{DOC} + \text{DOC}_F * F * \frac{16}{12} - R\right) * (1 - \text{OX}) \tag{12.1}$$

where

CH_4 Emissions Gg/year	Total emissions of Methane in the mentioned year
MSW_T	The total solid wastes disposed in the mentioned year
MSW_F	The portion of solid wastes removed to the landfill in Syria is taken 0.8 [2]
MCF	Methane correction factor

DOC	Degradable organic carbon
DOC_F	Fraction of degraded organic carbon
F	Fraction of Methane in landfill gases (default factor is 0.5)
R	Recovered methane gas Gg/year
OX	Methane oxidation factor (default value is 0)

12.2.1 The Selection of Emission Factors Used as Input Constituents of the Equation to Calculate Landfill Methane Production

12.2.1.1 MCF

Methane correction factor is defined as the amount variations of methane emissions generated per unit from uncategorized solid waste disposal sites—they were categorized according to the guidelines of IPCC related to national lists for classifications of global warming [13].

(a) **Anaerobic managed solid waste disposal sites**

Where solid wastes must have been controlled, that is, they have been directed to specific deposition areas where it will include cover material, mechanical compacting, and leveling of the waste so that the MCF to be used is (1).

(b) **Semi-aerobic managed solid waste disposal sites**

Where solid wastes must have been controlled, that is, they have been directed to specific deposition areas where it will include permeable cover material so that the MCF to be used is (0.5).

(c) **Deep unmanaged solid waste disposal sites**

They comprise all disposal sites which have depths of greater than 5 m so that the MCF to be used is (0.8).

(d) **Superficial unmanaged solid waste disposal sites**

They comprise all disposal sites which have depths of less than 5 m so that the MCF to be used is 0.4

(e) **Uncategorized solid waste disposal sites**

Only if countries cannot categorize their disposal sites into above four categories of managed and unmanaged solid waste disposal sites so that the MCF for this category to be used is (0.6).

Methane correction factor of each category is shown in Table 12.1.

Taken into consideration the specific nature of Tartous solid waste disposal sites which exceed 60 of random and uncategorized sites according to IPCC guidelines, therefore the MFC to be adopted is (0.6) due to the specificity of the studied sites.

Table 12.1 Methane correction factors (MCF) according to the sites disposal of SW classification

Site category	MCF
Anaerobic managed	1
Semi-aerobic managed	0.5
Deep unmanaged	0.8
Superficial unmanaged	0.4
Uncategorized	0.6

Table 12.2 Distribution of the samples over the year

Season	Month	Sample no	Sample repetition
Summer 2014	June–July–August	3	3
Autumn 2014	September–October	2	3
Winter 2014/2015	January–February	2	3
Spring 2015	April–May	2	3

12.2.1.2 Degradable Organic Carbon (DOC)

The evaluation of Degradable Organic Carbon in solid wastes is based on the composition of SWs and the content of Degradable Carbon of each component. Thus, Eq. (12.2) has been used to calculate DOC [12].

$$\mathrm{DOC} = \sum_i (\mathrm{DOC}_i * W_i) \tag{12.2}$$

where

DOC Degradable organic carbon in solid wastes, it is expressed as Gg C per Gg waste.

DOC_i Fraction of degradable organic carbon in waste type *i* Gg carbon/Gg SW(wet weight basis%) the default values are taken for each component of local municipal solid waste disposal sites in reference to IPCC model table, i.e., 40% for paper, 24% for textiles, 15% for food wastes, 43% wood, 20% garden wastes, and 24% diapers [14].

W_i Fraction of waste type i of the studied wastes.

Samples solid wastes were obtained from Tartous in the purpose of studying the specific composition. The studied samples were taken from solid wastes that were disposed of directly to Wadi Elhadi plant via tractors without passing any other transfer station. The weight of the sample was 500 kg during four seasons from June 2014 till May 2015. Table 12.2 reveals the temporal categorizing of the studied samples of solid wastes that were taken over a year. Using the Excel, the average composition of Tartous municipal solid wastes is shown in Table 12.3 and Fig. 12.2.

The proportion of garden wastes was calculated through monthly generation count of dump trucks from Tartous over the study period, where the volume of each dump

Table 12.3 Average composition of municipal solid waste in Tartous Governorate

Constituent	Percentage %
Plastics	12.98
Textiles	4.6
Metals	3
Wood	1.41
Paper and cartoon	5.3
Glass	2.82
Food wastes	66.56
Paper hand towels and sanitary napkins	3.33
Total	100

Table 12.4 Monthly generated amount of garden wastes

Year	Month	Trucks no	Weight/Ton
2014	June	167	122.745
	July	156	114.66
	Aug	123	90.405
	Sept	119	87.465
	Oct	178	130.83
	Nov	207	152.145
	Dec	211	155.085
2015	Jan	159	116.865
	Feb	163	119.805
	March	223	163.905
	April	166	122.01
	May	140	102.9
Monthly average		168	123.5

truck was 7 m^3, and the density of garden wastes was 105 kg/m^3 [15]. Table 12.4 shows the monthly generated amount of garden wastes. The percentages were calculated from the monthly average amounts of Tartous solid wastes as shown in Table 12.5, to which the percentage of garden wastes was 2%.

The following showed result was achieved by applying the formula from [2],

$$\mathrm{DOC} = \left(\frac{4.6}{100} * \frac{24}{100}\right) + \left(\frac{1.41}{100} + \frac{43}{100}\right) + \left(\frac{5.3}{100} * \frac{40}{100}\right) + \left(\frac{66.56}{100} * \frac{15}{100}\right) + \left(\frac{3.33}{100} * \frac{24}{100}\right) + \left(\frac{2}{100} * \frac{20}{100}\right)$$

$$\mathrm{DOC} = 0.15\ (\mathrm{Ggrcarbon/Ggrwaste})$$

Table 12.5 Monthly generated amount of municipal solid wastes in Tartous Governorate

Year	Month	Amount Ton/month
2014	June	6200
	July	6500
	Aug	6600
	Sept	6200
	Oct	6000
	Nov	5800
	Dec	5900
2015	Jan	6500
	Feb	5900
	March	6900
	April	6100
	May	6300
Monthly average		6241.67

12.2.1.3 The Fraction of Degradable Organic Carbon (Degraded) DOC_F

DOC_F represents the degraded fraction of degradable organic carbon and reflects the fact that organic carbon cannot be degraded or degraded slowly under anaerobic conditions at solid waste disposal sites. Thus, according to IPCC guideline, the value of DOC_F used in the study was 0.77 [9] which was adopted for the solid wastes in Syria [3] where the organic fraction and humidity were found to be high in Syria municipal solid wastes.

12.2.1.4 Methane Fraction in the Generated Gas (F)

Most solid wastes generate gases where methane in landfills forms 50% of the total volume. High fat and oil content wastes contribute to the higher rate of methane fraction which exceeds 50% so that it is recommended a methane fraction in landfills equals to 0.5 according to the IPCC 2006 waste model [13].

12.2.1.5 Recovered Methane Fraction (*R*)

Methane is generated at solid waste dumping sites. Its content can be expressed as *R* in the equation of methane emissions from dumping sites. As for Tartous landfills, there was no methane recovery, and the default value for CH_4 recovery was zero [9].

12.2.1.6 Methane Oxidation Factor (OX)

Oxidation factor reflects the amount of methane that results from the microbial oxidation of solid wastes in the landfill cover soil. The capacity for methane oxidation ranges from low to a maximum rate of methane generation, that is, methane oxidation is directly affected by the thickness, physical characteristics, and moisture content of soil cover. Studies reveal that oxidation factor is highly different between sites with good aeration and thick soil cover, sites with no soil cover, and sites of large content of methane which can escape through cracks in the cover. The default value of oxidation factor equals zero in uncategorized disposal sites as is the case with Tartous landfills, and thus, a value of 0.1 was used for oxidation factor and can be attributed to covered SWDS with good management of emitted and escaped methane estimation through cracks in the cover [13].

12.2.2 The Calculation of Methane Amount After Mechanical and Biological Treatment

Equation reported in the IPCC guidelines was to be used to calculate emissions after mechanical and biological treatment assuming small volumes of emissions during mechanical treatment [13]. Emissions after biological treatment are calculated according to equations mentioned in the IPCC guidelines 2006 related to national lists for classifications of global warming gases [16]:

$$\mathrm{CH_4\ Emissions} = \sum_i (\mathrm{M}_i * \mathrm{EF}_i) * 10^{-3} - R \tag{12.3}$$

where

CH_4 Emissions	CH_4 emitted in a year, Gg of methane
Mi	Mass of organic solid wastes to be treated according to the adopted treatment type *i* Kg (I is the product of multiplying the total wastes that are annually generated and the ratio 66.56%, which represents an organic fraction in Tartous wastes to be biologically treated).
EF	Emission factor for treatment i g(methane)/kg (treated wastes)
I	Fertilizer generation, anaerobic digestion
R	The total amount of CH4 recovered in a year Gg of methane (it equals zero since there is no recovery for methane at Elhadi plant)

- **The selection of methane emission factor (EF)**

Emissions resulted from fertilizer generation depend on many factors such as the type of wastes, temperature, water content, and aeration. As for EF of methane from wet wastes which were subjected to biological treatment (fertilizer production) at Elhadi plant, the adopted value for EF was 4 based on Table 12.6 as reported in the

IPCC guidelines 2006 related to national lists for the classification of global warming gases.

Value of EF was calculated upon carbon content in an organic fraction of solid waste in Tartous Governorate, for that four samples of organic waste, which would be subjected to biological treatment, were taken to define their moisture and organic carbon content. Depending on that, the values of EF in Table 12.6 must be considered according to the treatment method.

Tables 12.7 and 12.8 show moisture and organic carbon content of municipal waste in Tartous Governorate.

Total percentage of volatile compounds was calculated from Eq. (12.4) from [17]:

$$\text{Total percentage of volatile compounds (dry weight)} = \frac{M_{\text{VM}} - M_{\text{DRY}}}{M_{\text{TARE}} - M_{\text{DRY}}} \quad (12.4)$$

M_{DRY} The weight of the dried sample at 105 °C with the crucible in g
M_{DRY} The weight of the incinerated sample at 550 °C with the crucible in g
M_{TARE} Tare weight of empty crucible (g)

12.3 Results and Discussions

12.3.1 Methane Emissions from Municipal Solid Waste Landfills

Calculations were done using equations as reported in PCC guidelines, and according to module 6 Waste IPCC 1996, Tables 12.9, 12.10, 12.11, and 12.12 fill in the purpose of facilitative calculation.

12.3.1.1 First Step

Calculate the total solid wastes transported to landfills since the individual waste generation equals to 0.5 kg/capita/day [3], and municipal waste factor equals 0.8 [3] (see Table 12.9).

12.3.1.2 Second Step

- Input methane correction factor MCF = 0.6 to the column B of Table 12.10.
- Input decomposable organic carbon percentage DOC = 0.15 to the column C of Table 12.10.
- Input decomposed organic carbon percentage OC_f = 0.77 to the column D of Table 12.9.

Table 12.6 Default emission factors for CH_4 and N_2O from biological treatment of wastes

Type of biological treatment	Methane emission factor g (methane)/kg (treated wastes)		Nitrous emission factor g (methane)/kg (treated wastes)		Notes
	On a dry weight basis	On a wet weight basis	On a dry weight basis	On a wet weight basis	
Fertilizer production	10 (20–0.08)	4 (8–0.03)	0.6 (1.6–0.2)	0.3 (0.6–0.06)	Assumptions for treated wastes: • 25–50% biodegradable organic carbon in the dry body • 2% Nitrous in the dry body • Moisture content 60% • The emission factors for dry wastes are estimated from emission factors for wet wastes assuming a moisture content of about 69% in wet wastes
Anaerobic decomposition at biogas plants	2 (20–0)	1 (8–0)	Assumed to be negligible	Assumed to be negligible	

Table 12.7 Moisture content in the organic fraction of municipal waste in Tartous Governorate

Repetitions	The weight of an empty evaporating dish (g)	The weight of the sample (g)	The weight of the sample and evaporating dish before drying (g)	The weight of the sample and evaporating dish after drying (g)	The weight of the sample after drying (g)	Moisture content %
1	64.63	66.48	131.11	86.28	21.65	67.43
2	58.11	58.26	116.37	79.86	21.75	62.65
3	58.19	68.46	126.65	89.03	30.84	54.96
4	62.69	62.56	125.25	83.35	20.66	66.97

Table 12.8 Organic carbon content in the organic fraction of municipal waste in Tartous Governorate

Repetitions	The weight of the dried sample (g)	The weight of empty evaporating dish (g)	The weight of the dried sample and evaporating dish (g)	The weight of the sample and evaporating dish after incineration	Total volatile solids content % (on the basis of dry weight) (% DS)	Organic carbon content % (on the basis of dry weight) (% DS)
1	21.65	64.63	86.28	68.68	81.29	47.151
2	21.75	58.11	79.86	61.49	84.46	48.97
3	30.84	58.19	89.03	61.94	87.84	50.95
4	20.66	62.69	83.35	66.08	83.59	48.48
Average					84.3	48.89

Table 12.9 Calculation of the total amount of municipal solid waste disposed of in landfills

Year of inventory	Population	The average rate of individual waste generation (kg/capita/day)	Annually generated municipal solid wastes (Gg)	The disposed part of municipal solid wastes in landfills	Total disposed amount of municipal solid wastes in landfills (Gg)
	A	B	C	D	E
2010	786,760	0.5	143.584	0.8	114.867
2011	886,366	0.5	161.762	0.8	129.409
2012	989,765	0.5	180.632	0.8	144.506
2013	1,027,148	0.5	187.455	0.8	149.964
2014	1,062,997	0.5	193.997	0.8	155.198
2015	1,117,556	0.5	203.954	0.8	163.163

Table 12.10 Calculation of annually emitted amount of methane from municipal solid waste disposed of landfills of Tartous Governorate

Year	First step	Second step							Third step		
	A	B	C	D	E	F	G	H	J	K	L
	Total disposed amount of municipal solid wastes in landfills (Gg)	MCF	DOC	DOC_F	CH_4 fraction of the generated gas	Conversion factor	CH_4 potential percentage per solid waste unit (Gg/methane per Gg/solid waste)	Released CH_4 from solid wastes (Gg/methane per Gg/solid waste)	Annually emitted CH_4 (Gg)	Annually recovered CH_4 (Gg)	Net amount of Annually emitted CH_4 (Ton/year)
2010	114.87	0.6	0.15	0.77	0.5	16/12	0.08	0.05	5.7433	0	5743
2011	129.41	0.6	0.15	0.77	0.5	16/12	0.08	0.05	6.4704	0	6470
2012	144.51	0.6	0.15	0.77	0.5	16/12	0.08	0.05	7.2252	0	7225
2013	149.96	0.6	0.15	0.77	0.5	16/12	0.08	0.05	7.4981	0	7498
2014	155.19	0.6	0.15	0.77	0.5	16/12	0.08	0.05	7.7598	0	7760
2015	163.16	0.6	0.15	0.77	0.5	16/12	0.08	0.05	8.1581	0	8158
Amount of solid wastes submitted to Elhadi plant during the study period 20.002 Gg		0.6	0.15	0.77	0.5	16/12	0.08	0.05	1	0	1

Table 12.11 Methane emissions from Tartous Governorate wastes from 2010 to 2015 when MBT was being used

Year	Amount of generated solid wastes (Gg)	Mass of organic solid wastes subjected to treatment (Mi) (Gg)	Emission factor for methane treatment (EF)	The total amount of recovered methane (*R*) (Gg CH_4)	CH_4 emissions (Gg CH_4)
2010	143.5837	95.627	4	0	0.383
2011	161.761795	107.733	4	0	0.431
2012	180.6321125	120.301	4	0	0.481
2013	187.45451	124.845	4	0	0.499
2014	193.9969525	129.202	4	0	0.517
2015	203.95397	135.833	4	0	0.543

Table 12.12 Methane emissions from solid wastes submitted to Elhadi plant during the study period

Amount of solid wastes submitted to Elhadi plant during the study period (Gg)	Mass of organic solid wastes submitted to Elhadi plant during the study period (Mi) (Gg)	Emission factor for methane treatment (EF)	The total amount of recovered methane (*R*) (Gg CH_4)	CH_4 emissions (Gg CH_4)
20.002	11.581	4	0	0.0463

- Input methane fraction in the generated gas 0.5 to column E of Table 12.10.
- Calculate the methane fraction released from the waste unit by multiplying of values of columns C, D, E and conversion factor of carbon into methane (12/16) and the result were to be input in column G of Table 12.10.
- Calculate the methane fraction released from the waste unit by multiplying of values of columns B, G and the result were to be input in column H of Table 12.10.

12.3.1.3 Third Step

- Obtain the annual emission of methane by multiplying values of columns A and H so the result is to be input in column J of Table 12.10.
- The annual recovered content of methane to be input in column K of Table 12.10.
- Obtain the net content of annual emitted methane by subtracting k column value from that of J, and the result is to be input in column L of Table 12.10.

Table 12.13 Reduction in Methane emissions from Tartous Governorate wastes from 2010 to 2015 when MBT was being used

Year	CH_4 emissions (Gg CH_4)			Methane reduction due to MBT (Ton CH_4)
	Solid waste landfilling	MBT	Reduction	
2010	5.743	0.383	5.361	5361
2011	6.470	0.431	6.039	6039
2012	7.225	0.481	6.744	6744
2013	7.498	0.499	6.999	6999
2014	7.76	0.517	7.243	7243
2015	8.158	0.543	7.615	7615

Table 12.14 Reduction in emissions resulted from solid wastes submitted to Elhadi plant during the study period

CH_4 emissions resulted from solid wastes submitted to Elhadi plant during the study period (Gg CH_4)			Methane reduction due to MBT (Ton CH_4)
MBT	Solid waste landfilling	Reduction	
0.046	1.0001	0.954954	

12.3.2 Methane Emissions Resulted from Mechanical and Biological Treatment

Equation 12.3 as reported in IPCC guidelines was used to calculate emissions after mechanical and biological treatment assuming small volumes of emissions resulting from mechanical treatment [16]. Emissions resulted from mechanical and biological treatment of Tartous municipal solid wastes were determined during period ranges from 2010 to 2015 as shown in Table 12.11, and the same was applied to the emissions resulted from solid wastes which were transported to Elhadi plant as shown in Table 12.12.

12.3.3 Achieved Reduction of Methane Emissions

Comparing methane emissions resulting from landfilling solid wastes and that of mechanical and biological treatments of Tartous municipal solid wastes from 2010 to 2015 (see Table 12.13 and Fig. 12.3) on the one hand, and comparing the quantity of municipal solid wastes delivered to Elhadi plant during the study period (see Table 12.14 and Fig. 12.4). On the other hand, it was noticed a significant reduction in methane emission when mechanical and biological treatment was used (Fig. 12.5).

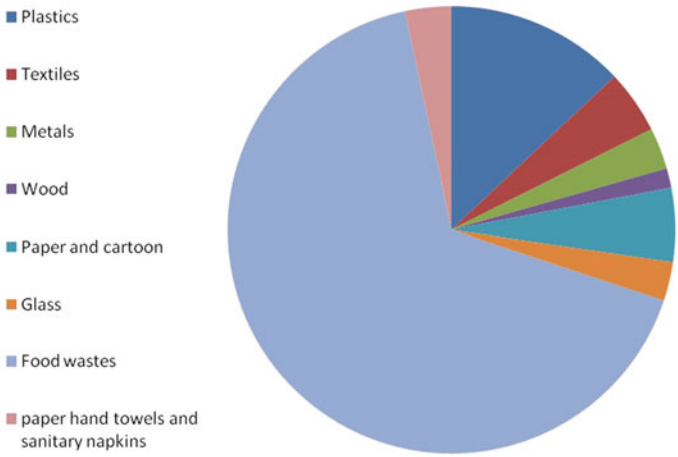

Fig. 12.3 Average composition of municipal solid waste in Tartous Governorate

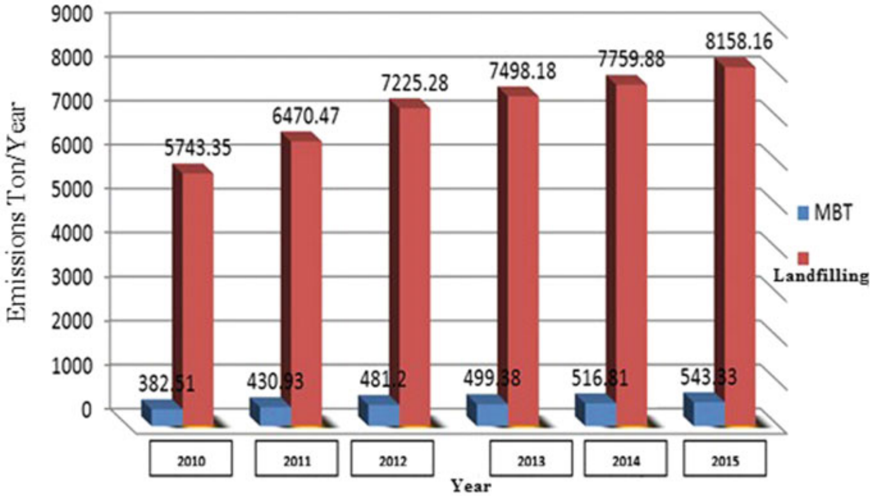

Fig. 12.4 Comparison of methane emission changes from Tartous solid wastes from 2010 to 2015 when MBT was used as an alternative to random landfilling

12.4 Conclusions and Recommendations

This chapter highlights the following conclusions and recommendations:

1. Organic fraction forms the largest part of Tartous municipal solid waste composition. Random waste landfilling contributes to higher methane emissions in proportion to the higher organic fraction.

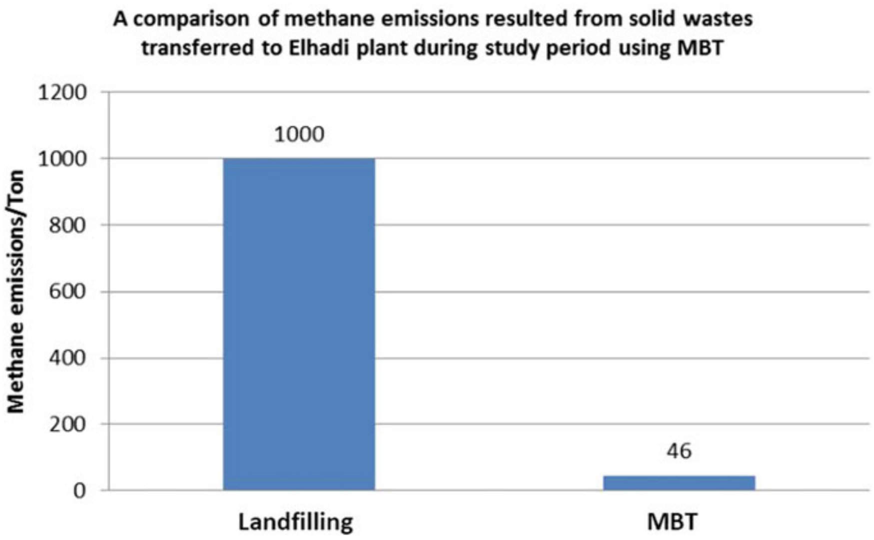

Fig. 12.5 Comparison of methane emissions from solid wastes submitted to Elhadi plant for MBT and under landfilling conditions

2. Methane emissions increased in Tartous during the period ranged from 2010 to 2015 due to random landfilling of the generated solid wastes during the mentioned period.
3. The adopted method of mechanical and biological treatment of MBT, by which the organic fraction of solid wastes can be transformed into fertilizers, has been considered an appropriate method to treat Tartous municipal solid wastes since they were not sorted from their source as well as they contain higher organic content.
4. Using mechanical and biological treatment can reduce methane emissions about 93% in comparison with random landfilling of solid wastes.
5. Making the Wadi Elhadi plant work at maximum capacity and continuously expanding it in order to treat the entire quantities of wastes generated in Tartous Governorate will stop the uncontrolled dumping of waste and thus contribute to the reduction in methane emissions and consequently the gradual reduction in air pollution in the tourist city.
6. To obtain the best results for reducing methane emissions resulted from municipal solid waste sector specifically in Tartous and generally in Syria, the process of integrated municipal solid waste management, which includes waste sorting at the place of origin, and processing of the sorting products must be applied on a case-by-case basis.

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Chapter 13
Thermal Sewage Sludge Disposal in Stationary Fluidized Bed Combustion DN 400 by Using Fuel BRAM (Fuel from Solid Waste)

Noama Shareef

Abstract One of the principles for future waste policy in Germany is the conversion of waste management into a material flow, energy and resources management. The objective is the use of all combustible materials for the replacement of primary fuels and thus a contribution to saving resources and to climate protection. The review covers the technical, economic and environmental conditions for local utilization of fuels derived from the waste in SFBC plant energy systems with a firing capacity of 6 MW. Pre- and fine-screening materials, the by-products from the RDF production, are disposed of. This is connected with known negative actions on the environment. The objective of this study was to observe the combustion process of different sludge's with BRAM (from solid waste as energy) in a stationary fluidized bed combustor (SFBC) and evaluate the chemical compositions of the flue gas emissions. The experimental test of three different sludges combustion in the 200 kW (Kilowatt) by 400 by using fuel BRAM (fuel from garbage as energy resource). The combustion system DN400 was designed to realize a self-sufficient combustion (energy self-sufficient) and to control the concentration of exhausted emissions like (O_2, CO, CO_2, NO, NO_2, SO_2, Corg, etc) by measuring it before it comes out of the system. The results in the following study showed very good control on the above emissions with respect to German emission limits 17BimSchV [15] also the technical process requirements in a temperature window must be limited to 850–880 °C, with respect to 17BimSchV. This study furthermore is applicable for the different sludges from different wastewater treatment technologies which have similar chemical compositions to the sludges tested and disposal cost by low-energy consumption.

Keywords Thermal sludge disposal · Stationary fluidized bubbling bed · BRAM · Thermal solid disposal · Heavy metals · Energy consumption · Stationary fluidized bed firing DN 400

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Abbreviations

tA	Start time
tE min	End time
Dt min	Duration
m * KS	Sludge mass rate (kg/h)
m * BRAM	BraM mass rate (kg/h)
m * Br	Total fuel rate (kg/h)
xKS	Ratio sludge/total fuel (kg/kg total fuel)
Sludge/BRAM	Ratio sludge/BRAM (kg sludge/kg BRAM)
Q * thermal	Thermal power (kW)
T SFBC	Temperature of the SFBC (°C)
BImSchV	Federal Immission Control standard
BraM	Fuel from garbage/waste
FB	Free board
TR	Dry mass (%)
KS	Treated sludge (Dm)
SWSF	Stationary fluidized bed combustion
yO2	Proportion of the gas component in the gas mixture [%V][ppm]
xKS	Part of the sewage sludge in the mixed fuel (kg/kg)
BP	Operation point
Hu	Lower calorific value (Kw)
A	Heat transfer coefficient (W/m^2 K)
H	(Pa s)
Br	Fuel
t	Tonne
A	Area
A	Thermal diffusivity (m^2/s)
V%	Volume procent
RG	Flue gas
TMW	Daily mean value (emission)
EBS	Alternative fuel
E	Emission
K	Component (elemental analysis)
HMW	Half-hourly average (emission)
LuVo	Air preheating
WÜ	Heat exchanger
KrW-/AbfG	Circular Economy and Waste Standard
WS	Fluidized bed
RI-Fließbild	Pipeline and instrument flowchart
EW	Population equivalents

13.1 Introduction

Due to the rapid development of the pharmaceutical industry and the increasing consumption of emerging contaminants such as personal care products, the composition of pollutants contained in municipal wastewater has changed over the last years. The composition now includes organic compounds, oil products, suspended particles, heavy metals, pathogenic substances and chemical contaminants [2].

As an alternative disposal variant, the thermal salvage/disposal of sewage sludge is to be presented below [3]. Therefore, the technological solutions to deal with sludge and waste management must satisfy sanitary and environmental purposes. And because phosphorus is a limited non-renewable resource that is indispensable as an essential nutrient for the growth of organisms in most ecosystems. Therefore recovering it from sludge and reuse of phosphorus resources from sewage sludge ash is a successful technology [4]. It was revealed that phosphorus can be selectively leached from solid gasification residue with high efficiency (73–82%), [5].

Sewage sludge use and disposal in Germany: Municipal sludge and waste management systems are becoming more complex in many countries with the move from landfill-based to resource recovery-based solutions following the setting of international and national targets to divert waste from landfill and to increase recovery rates or to insure the suitable safely disposal [6].

In the Federal Republic of Germany, between 2.3 and 2.7 million tonnes of sewage sludge dry mass are produced every year, this result is about 1.7/E * d secondary-treated sludge and about of 0.721/E * d primary sludge. Sewage sludge production is estimated at about 37 kg per inhabitant and year [7]. Form the listed information about sludge quantity in Germany. It can be expected that 675,000 ton dry Mass (t.dm) from sewage sludge to about 1 million (40% reused in agriculture).

To know the sewage sludge disposal methods in Germany, the references refer that at the beginning of the 1980s until the middle of the 1990s, the majority of the sewage sludge was deposited in Germany. This changed with the new solid waste disposal in Germany and the adoption of the Technical Instructions for Municipal Waste and increasing also the thermal disposal of sludge in Germany. Figure 13.1 shows the development of sewage sludge disposal in recent years.

In Germany, between 2.,3 and 2.,7 million tonnes of sewage sludge dry mass per year are produced. Due to the current considerations of the limit values of the sewage sludge after the standards AbfKlärV, agricultural and landscape conversion has again become the focus of a controversial discussion on environmental policy [8].

This increases the interest of the decision makers in the thermal disposal technologies, even it is expensive, but this offers a high disposal security in the future (see Fig. 13.2).

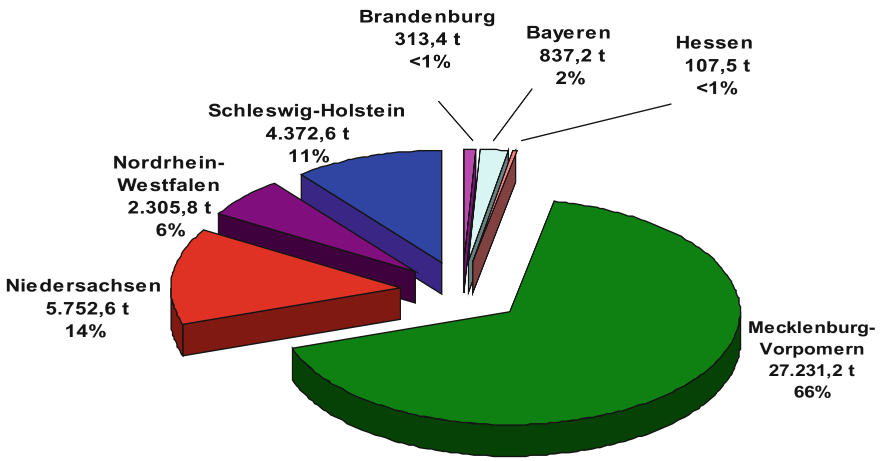

Fig. 13.1 Agricultural—used sewage sludge in German provinces in [6]

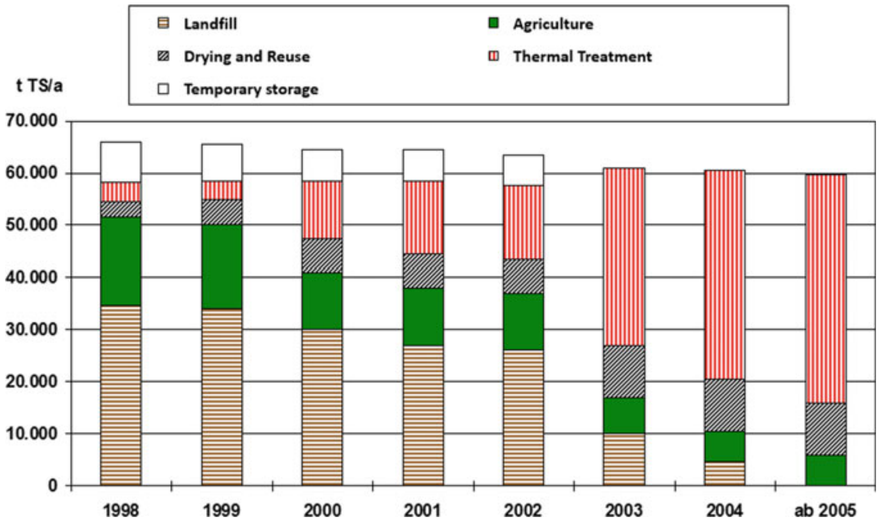

Fig. 13.2 Sludge disposal in Germany between 1998 and 2005 (Sludge t.d.m/y) [8]

13.2 Materials and Methods

13.2.1 Study Materials

In the Arab region, and especially here in Syria, there is no experience in thermal disposal of untreated or unacceptable sludge. The current sewage sludge disposal in Syria is mainly landfill in addition to reuse it for agricultural purposes. Wastewater

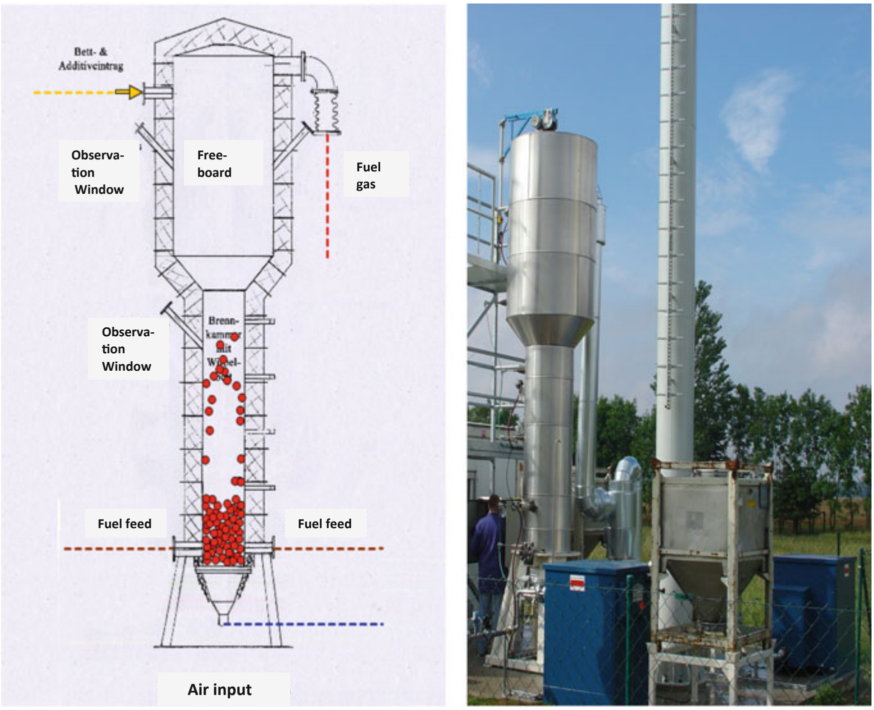

Fig. 13.3 Schematic view of the Stationary fluidized bed firing SWSF DN 400, at the test hall, Environmental Engineering, University of Rostock, Germany [14]

and sewage sludge are also contaminated by a large number of industrial inputs (oil refineries, textile industries, fertilizer plants, etc.) [9]. In Europe, the results of the current sewage sludge policy are evident as a reactor dump and in heavy metal-contaminated agricultural areas. As an alternative disposal variant, therefore, a 100-kg sample of dry raw sewage sludge from Homs wastewater treatment plant was taken to the laboratory of the Department of Environmental Engineering, University of Rostock, where it was burned in a small combustion reactor at 850 °C with the help of BRAM (special solid waste) as additional fuel [10].

Stationary fluidized bed firing DN 400: The fluidized bed combustion is operated by low power (200 kW) as a bubble-forming furnace with air preheating. See Fig. 13.3.

The fluidized bed fuels are introduced separately with delivery units against the pressure of the fluidized bed directly into the fluidized bed. The reactor space is divided into the combustion chamber with the fluidized bed and freeboard (expansion of the reactor for the regulation of flue gas velocity and solids discharge). Figure 13.3 shows the design plant with the reactor structure and the entry points in the system.

The process philosophy at the Department of Environmental Engineering is the fixation of the combustion reaction in the lower part of the reactor, the combustion

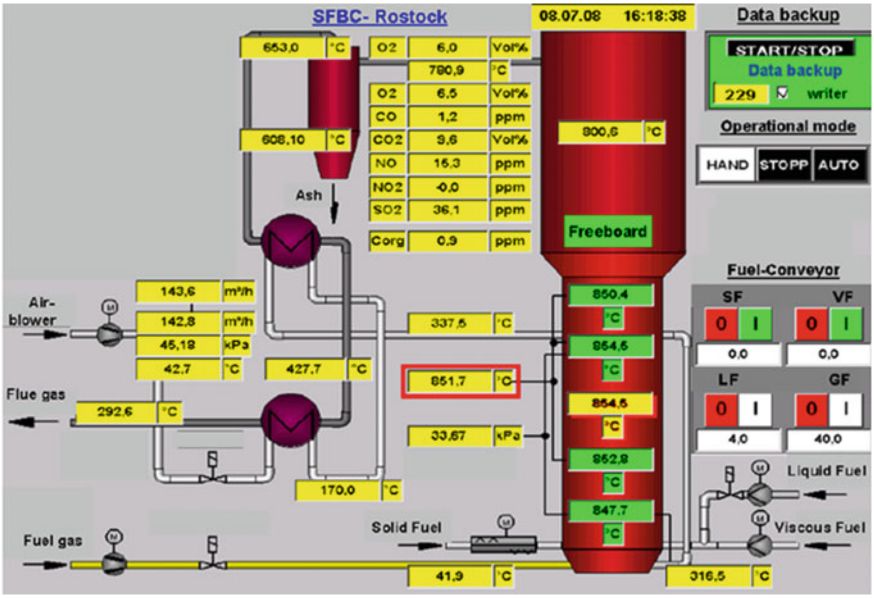

Fig. 13.4 Screen of the Remote Control Computer, University Rostock [10]

chamber because the reaction can be very good controlled here. The legal and procedural process requirements result in a temperature window of 850–880 °C, which must be observed with respect to [1]. The upper limit is required to carry out desired primary flue gas treatment by additives.

The plant is designed at the Department of Environmental Engineering at University of Rostock, Germany, on a semi-technical scale for research, and it was applied in several places and for several countries by Prof. Steinbrecht.

For comparison, four more sludge samples from German wastewater treatment plants in several treatment technologies were burned also using the same procedure. It has shown that this principle of action is excellent for the qualified energy use of waste materials. Various experiments of the applicability of the principle were successfully done at “Stationary bubble-forming vertebral layer firing” which demonstrated in the thermal use of waste.

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Table 13.1 Heating value and elementary analysis of BRAM (exemplary)

Component	BRAM (Samtens)
c [kg/kg]	0.4000
h [kg/kg]	0.0559
o [kg/kg]	0.1535
n [kg/kg]	0.0132
s [kg/kg]	0.0016
a [kg/kg]	0.3015
w [kg/kg]	0.0744
Σ [kg/kg]	1.0000
Hu [MJ/kg]	15,593
Ho [MJ/kg]	17,003

the thermal use of waste. Figure 13.4 shows the technological flow sheet of SFBC at the CET, Germany [10].

It has shown that this principle of action is excellent for the qualified energy use of waste materials. Various experiments of the applicability of the principle were successfully done at "Stationary bubble-forming vertebral layer firing" which demonstrated in the thermal use of waste. A prototype for the disposal of gaseous residues was proving itself in practice. Control and regulation of the plant are operated via a computer. The actors and sensors used in this work show Table 13.1 and Fig. 13.4. These quantities are used under its respective general abbreviation in this description.

13.2.2 Methods of Analysis

Sludge samples were collected from different wastewater treatment plants in different treatment technologies from two countries and burned in the dehydrated (not dried) condition. In this wet, pumped condition, the calorific value of the sludge is negative, therefore, and as an energy carrier for the process, EBS (Brikettierter substitute fuel) is used, several different sludges were tested:

- Anaerobic-treated sludge wastewater treatment plant in Rostock, Germany.
- Raw sludge wastewater treatment plant in Homs, Syria.
- Reed bed sludge wastewater treatment plant in Stralsund, Germany.

To demonstrate a decentralized thermal sludge disposal concept, it was used to compare with sludge from raw sewage treatment plant, Homs, digested sludge from the sewage treatment plants in Rostock as well as digested sludge from the wastewater treatment plant Mühlbach, Stralsund, burned in a stationary fluidized bed furnace (SWSF).

As auxiliary fuel, thigh-calorific residual waste was used as fraction 4 (BRAM), which is subjected to the utilization requirement. Here in this system, the temperature is controlled automation, and all other processes were tested by using a computer connected with the system above.

Since both fuels are considered as waste, the procedure is regulated by the 17BimSchV (federal emission control regulation: incineration of waste and waste substances) (Shareef and Exchtaedt [11]).

13.3 Characterization of the Process and the Fuels

In addition to the use of BRAM (fuel from waste) as an auxiliary fuel, the process presented here offers various advantages. Due to the high mixing of bed material and fuels, as well as the good heat transfer, the fuels are converted very completely with low emissions.

The process can minimize avoidable emissions (CO, Corg and NOx). Figure 13.5 shows effects on the process itself.

Unavoidable emissions such as sulfur and chlorine gases can be controlled easily and inexpensively/washing by adding additives to the combustion chamber. The process reduces the mass of the treated fuels to its ash content (after fuel mixture and water fractions in the sewage sludge: 25–17% by weight of the starting mass). Almost complete oxidation of the organic fuel components is achieved. The use of process heat is currently not integrated into the process, which makes such a process energy-independent from where it can be designed.

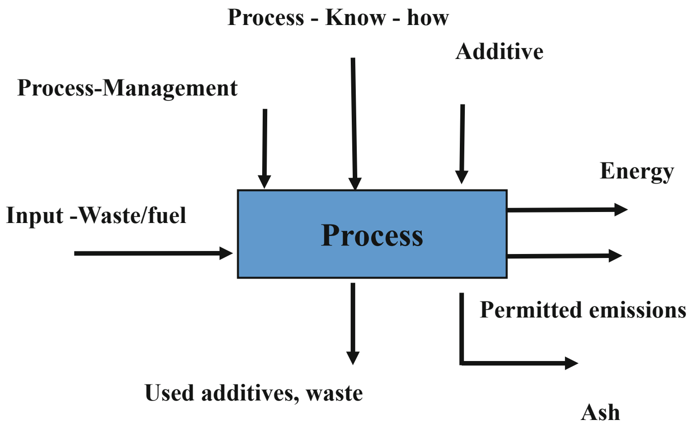


Fig. 13.5 Influence/effects on the SWSF process itself [11]

"Primary" measures to reduce emissions: For primary treatment, desulphurization in SWSF with limestone granules, extensive experimentally assured experience is available at the Department of Environmental Technology from previous research.

$$CaCO_3 \rightarrow CaO + CO_2 \text{ Thermal detection in the vertebral layer}$$

$$H_2S + 3/2O_2 \rightarrow SO_2 + H_2O \text{ ombustion in the vertebral layer}$$

$$SO_2 + 1/2O_2 + CaO \rightarrow CaSO_4 \text{ Schadstoffeinbindung in der Wirbelschicht}$$

Limestone granules can be reliably transported to the SWSF reactor even in a numbered state with a snail conveyor [12]. The limestone is thermally opened up "in flow balance," fine particles CaO is formed. The CaO reacts with the SO_2 and oxygen to fine particle-like $CaSO_4$, which is continuously carried out of the layer with the combustion fumes.

13.3.1 Fuel from Garbage-BRAM

The raw material from waste (also secondary fuel or high-calorific household waste fraction) is produced by applying different separation techniques from household waste. It is sourced from the replacement recycled solid waste as fuel production of the company NEHLSEN for safe support the combustion chamber BRAM has been developed since the beginning of the 1970s and, against the background of resource conservation, are to replace the so-called standard fuels in industrial combustion systems [hence: substitute fuels (EBS)].

Compared with their starting material (waste), they have a higher and uniform calorific value, lower water content and a lower pollutant load [13]. Proof of stable, self-contained combustion of the mixed fuel BRAMSK within the legal limits must be provided. For this purpose, self-contained combustion with the auxiliary fuel is first realized the energy carrier of the combustion BRAM (see Fig. 13.6). Table 13.1 characterizes the characteristics of such fuel.

The solid heating value of such a fuel enables its energetic use of garbage as the main energy source of the described process. On the other hand, there is the pollutant load of this residual substance, which is mainly characterized by a heavy metal concentration in the fine grain range.

Then the sewage sludge is added by means of a slurry pump (see Fig. 13.7); it is digested sludge from WWTP Rostock, Germany. Different loads were controlled in several points in relation to the mixing ratio. The fuel output and the measured values of the combustion (temperature, mass flows and pollutant concentrations in the flue gas) were also documented for evaluation.

Fig. 13.6 BRAM pellets and starting material

Fig. 13.7 Conveyor test, pumped digested sludge

13.3.2 Sewage Sludge from Different Countries

The experimental fuel is sewage sludge from the wastewater treatment plant in Homs, Syria. It is from municipal wastewater with industrial content (sugar, yeast, edible oil, soap, and alcohol production, Homs Petroleum Refinery, textile industry, metal processing, etc.). The raw sludge produced during wastewater treatment does not receive any further treatment in addition to conditioning (with polyelectrolytes) and subsequent drainage (on TR = 30 M%). It should be noted that the sludge state when it is leaving the wastewater treatment plant in Homs resembles the Rostock sewage sludge in heating value and water content. Here, therefore, the positive experiences in previous experiments with the German mud can be used. For the combustion test, the dried sewage sludge (delivery state: TR = 95 M%) is water down to eligible trial (TR = 42 M%; heating value, Hu = 4.15 MJ/kg) diluted. Table 13.2 shows the elementary analysis and heating value of the untreated sewage sludge from Syria compared to treated sewage sludge from Germany, Rostock (EURAWASSER NORD

Table 13.2 Tested different sludges elementary analysis and heating value sewage sludges

Component	Untreated sludge (WWTP Homs, Syria)	Treated sludge (WWTP Rostock, Germany)
c [kg/kg]	0.3497	0.3100
h [kg/kg]	0.0452	0.0490
o [kg/kg]	0.1030	0.2279
n [kg/kg]	0.0350	0.0450
s [kg/kg]	0.0001	0.0120
a [kg/kg]	0.4670	0.3561
w [kg/kg] =	0.0000	0.0000
Σ [kg/kg] =	1.0000	1.0000
Hu [MJ/kg] =	13.26	12.44
Ho [MJ/kg]	14.25	13.51

GmbH). Table 13.2 shows elementary analysis and heating value sewage sludges from Germany to Syria.

It is striking that the untreated Syrian sewage sludge has a heating value that would show it equal to treated sludge from Germany, Rostock [see heating value sewage sludge Rostock (anaerobic treatment)]. This can be attributed to the lower cellulose content in the wastewater of Arab countries. Nevertheless, the Syrian sludge performs higher than the Rostock sludge compared to + 0.82 MJ/kg. Furthermore, the higher ash content is clear, which is due to the separation performance of the sand catch [11]. Testing for heavy metals using chemical disclosure provides the following values. The contrast with previous analyses of sewage sludge from Homs by various laboratories in Table 13.3 shows a rather inconsistent picture. This can be attributed to seasonal fluctuations in wastewater quantity and quality.

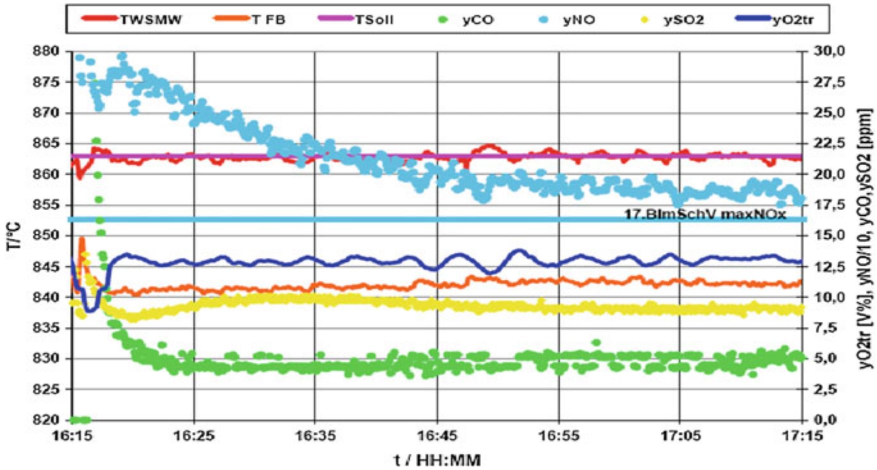
Compared to literature data from the Rostock sewage sludge, the Syrian values show up and partly exceed the limits (mercury) of the German waste sewage sludge regulation (waste wastewater treatment V) for the application of sewage sludge to agricultural regulations.

13.4 Results and Discussions

The results of the experiment are listed below. The procedure was evaluated with regard to the regulation based on temperature, oxygen and emission history. Chlorine gas and sulfur gas pollution of the flue gases in such combustion were also regulated by means of additives. In order to clarify the disposal of the process residues, bed material and separated fly ash were tested for its content of heavy metals. So far, three different sewage sludges were used in the above experiment.

Table 13.3 Comparison of heavy metal for sewage sludge from Homs of different laboratories and test years

Pos.	Sample	Labor	Averaged heavy metal concentrations (mg/kg)								Source
			Pb	Cd	Cr	Cu	Ni	Hg	Zn	As	
1	1999	diverse	69.8	0.4	24	172	46	11.4	958	–	N. Shareef
2	2000	diverse	28.3	2.19	60	157.5	51	9.9	783	–	N. Shareef
3	2001	diverse	28.3	0.9	43	158	41	17	812	2.78	N. Shareef
4	11/2004	LUFA Rostock	80	1.1	63	236	41	8.87	1497		N. Shareef
5	4/2005	Lab. Uni-Rostock	16.8	16.8	77	12.6	852.6	–	56	–	Bartsch
6	Ave. (1-5)	–	44.64	4.278	53.4	147.2	206.3	11.79	821.2	2.78	
7	Ave. (1-4)	–	51.6	1.148	47.5	180.9	44.75	11.79	1013	2.78	



Test date	24.05.2005	U0	1,19 m/s	TWS	862,7 c	fuel performance	78kw
Start measuring	16:15:05	CO2	6,7 Vol%	T Air	405,2	combustion capacity	101kw
End measuring	17:16:54	Corg	0ppm	O2 ZIROX	10,3 Vol%	T	time
Duration (min)	62	CO	5ppm	O2tr	13,0 Vol%	t/c	Temperature
Throughput	34,99 kg/h	NO	205ppm	SO2	216 ppm	h.bed	1,10m
xKS	0.54kg/kg	NO2	10% of NO	h- bed (m)	1,10	fuel	KS/BRAM

Fig. 13.8 Operating diagram of the SWSF DN 400: BRAM combustion (sewage sludge from wastewater treatment plant Homs, Syria), operation point 3

13.4.1 Operating Characteristics

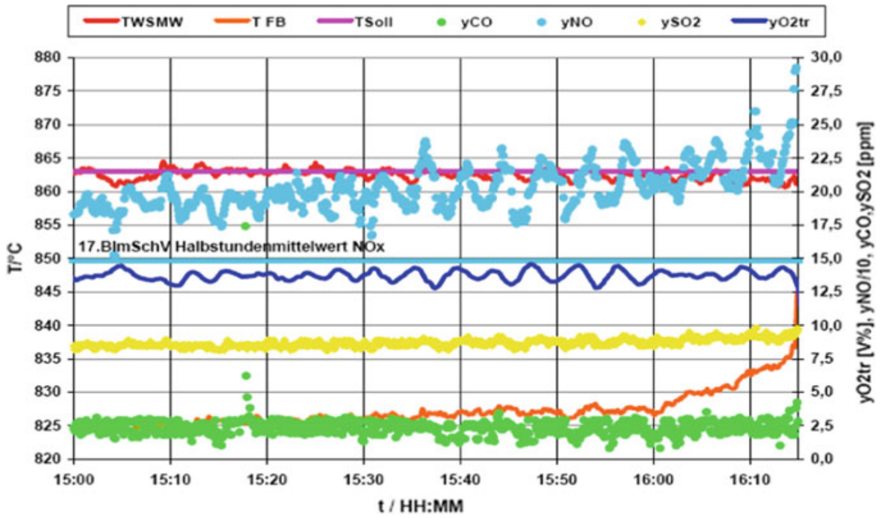
For the fuel BRAM, a controller parameterization is carried out according to the objective. This was checked for its functionality (see Fig. 13.8). The sewage sludge was pumped into the system (see Fig. 13.9).

Figure 13.8 shows the operating behavior and emissions for BRAM combustion. Nitrogen oxide emissions exceed the limit of the 17BimSchV. This emission is attributable to the fuel BRAM (see Figs. 13.8 and 13.9).

The system entry shock provoked by the sewage sludge can be easily identified by the oxygen concentration (yO2tr) and the emissions (ySO2, yNO, yCO) and the temperatures in Fig. 13.9 (16:15–16:20). Further, this figure shows that the combustion reaction takes a certain period to stabilize—to reach a quasi-stationary state ([11]; Beu 2007).

The subsequent addition of additional fuel (sewage sludge) results in a reduction of the supply of oxygen for the fuel nitrogen by oxidation of the carbon compounds. This effect reduces nitrogen oxide emissions.

Carbon oxidation is a thermodynamically spontaneous, exothermic reaction. In contrast, nitrogen oxidation is an endothermic reaction that requires energy. According to the law of mass action, with reduced concentration of starting materials (in this case O_2 as reactant), the reaction equilibrium shifts to the side of the starting materials (increased reverse reaction).



Test date	24.05.2005	U0	1,26 m/s	TWS	862,7 c	fuel performance	63kw
Start measuring	15:01:04	CO2	6,5Vol%	T Air	401,2	combustion capacity	84kw
End measuring	16:01:00	Corg	0ppm	O2 ZIROX	11,7 Vol%	T	time
Duration (min)	54	CO	3ppm	O2tr	13,7 Vol%	t/c	Temperature
Throughput	16,75 kg/h	NO	199ppm	SO2	9 ppm	h.bed	1,10m
xKS	0.00kg/kg	NO2	10% of NO	h- bed (m)	1,10	fuel	BRAM

Fig. 13.9 Operating diagram of the SWSF DN 400: BRAM combustion, operating point 2

These two circumstances increase carbon oxidation to the detriment of nitrogen oxidation. This leads to increased CO emission (imperfect oxidation state of carbon), which is also undesirable. Therefore, here is the right measure to find. The following data can be collected for the subsequent sewage sludge BRAM incineration (see Fig. 13.9). The operating point performed with a fuel input of m * Br = 35 kg/h with a sewage sludge content of xKS = 0.5382 kg/kg Br [fuel output Q * Br = 78 kW, firing rate Q * F = 101 kW (air preheating)] meets the conditions of the 17. BImSchV: Tmin = 850 °C at yO2tr, min = 6 V% were fulfilled (like in Fig. 13.8) The freeboard temperature remains below the bed temperature during the operating point. This criterion shows that the reaction could be fixed in bed during combustion. The measured emissions at this operating point are as follows (Table 13.4).

The incomplete oxidation products of the carbon can be minimized by the fluidized bed process and barely exhaust the limit values (threshold exhaustion: CO: 8%, C_{org}: 0%).

The NO/NO_2 exceeds the limit of the regulation clearly. In earlier tests with Rostock sewage sludge (test condition: TR = 16 M%), this position exploited approx. 22% of the limit value. The clear difference is explained by the higher TR content of the Syrian sludge mixture (TR or dry mass = 42 M%), which introduces more fuel nitrogen compounds into the process.

Furthermore, it can be seen from the data of the wastewater treatment plant Homs that the plant has no denitrification stage, which suggests a higher load of the sludge

Table 13.4 Sewage sludge-BRAM incineration emissions (BP 3 with limestone addition) after (17BimSchV)

	BP 3	BP 3	Limit value according to the German standard: 17BimSchV
Emission	O2tr. = 13 vol.%	Conversion to (O2tr = 11 V%)	(O2tr = 11 V%)
CO =	5 ppm	7.68 ppm	100 ppm (TMW)
C_{org} =	0 ppm	0 ppm	
NO =	205 ppm	547 ppm (NO_2 + NO)	200 ppm (TMW)
NO_2 =	20 ppm (10% v. NO)		
SO_2 =	9 ppm	32 ppm	50 (TMW)

BP: operating point, TR = dray mass

Table 13.5 Results of the chlorine gas measurement in the flue gas after [1]

	Chlorine gas emission stated as HCl: [mg/m^3(N) RG_{tr} (yO_{2tr} = 11 V%)]
Sample 1	204
Sample 2	310
Sample 3	325
Sample 4	372
Half-hour mean HMW (17. BImSchV)	**60**

with nitrate compounds and is another reason for the burden of the flue gases The effects mentioned under 4.1 on NO_x formation while lowering the oxygen supply could not be implemented here.

NOx emissions can be treated primarily with urea (in the firing chamber) or with ammonia in a fluidized bed furnace (in the flue gas). The dust emissions can only be estimated approximately by the difference in the mass balance. This emission exceeds the limit values of the 17. BImSchV and suggests a sufficient dimensioning of the dedusting method [16].

13.4.2 Harmful Gas Binding

During operation, marble chips (limestone) were introduced into the combustion chamber to bind the resulting sulfur and chlorine gases. The measured emissions (Table 13.5) prove this primary flue gas treatment for sulfur to be successful.

The chlorine gas emissions were measured separately for the BRAM combustion and show that the ideal stoichiometric ratio Ca/Cl still has to be found here.

13.4.3 Automation

The PI controller used is implemented as a programmed algorithm on the visualization interface of the master computer. He calibrates the control of BRAM production—the energy source of combustion. When sewage sludge is added, the regulator should keep the temperature at a constant level against the “disturbance” sewage sludge by adjusting the BRAM delivery. Figure 13.8 shows the operating behavior of sewage sludge BRAM combustion based on the main characteristics of the process (average reactor temperature, TWSMW, and oxygen concentration in dry flue gas, O_{2tr}).

13.4.4 Sampling of Process Residues Fly Ash and Bedding Material

The fly ash and the bed material used were sampled organic components and heavy metal concentration. The results are shown in Table 13.6.

Evaluation of the results of the analysis in Table 13.6 shows the high degree of burnout in the residual carbon content of the combustion ashes (average 0.006 M% organic dry residue).

The enrichment of sulfite/sulfate ions in the bed material, as well as the fly ashes, demonstrates the effectiveness of the primary flue gas desulfurization by limestone addition. The transport and separation of heavy metals in a fluidized bed furnace are determined by a variety of factors. The heavy metals are presented in different forms of bonding in the fuel.

Some of these metal compounds are released in the reactor, forming new compounds with reactants present (e.g., O, S, Cl) that condense to their specific dew points in the process. Furthermore, condensation and adsorption processes play a role in the ash particles formed during combustion. The SWSF fractionates the resulting ash particles (loaded with heavy metals) according to their density. The heavy metals are therefore bound to fine particles or in the gas phase, discharged with the flue gas, separated together with larger particles in the cyclone or remain in the bed material.

The bed material shows a higher concentration for all sampled heavy metals after experimentation (see Table 13.7). Also and the same case, the fly ashes are heavily loaded. Striking are the great differences in the pure BRAM combustion for BRAM-KS combustion. This can be explained as follows. First, the total ash flow in the system increases by the ash content of the sewage sludge, thus diluting it. Second, the amount of water vapor in the flue gas increases as a result of the sewage sludge entry, which leads to an increase in the flue gas volume flow and thus to increased particle discharge.

The disposal of the residues is determined by their pollutant content. The classification criteria of the landfill classes according to the Waste Deposition Ordinance (AbfAblV 1998) are assigned to the converted measured values of the process

Table 13.6 Analysis of process residues cyclone ash and bedding material

		Schwermetalle (mg/kg)								Rest-C	Ges. P	SO_3	SO_4
Pos.	Sample		Pb	Cd	Cr	Cu	Ni	Hg	Zn	[M%]	[mg/kg]		
1	Cyclone ash	E	0.1	18	2.4	0.5	1.3	8.75	6	0.007		2	110
	(BRAM + limest.)	A	216	140	94	4	638	137	900		3340		
2	Cyclone ash	E	0.4	14	14	0.3	1.1	0.8	4	0.004		4	680
	(BRAM/sludge)	A	24	120	60	2	2	10	40		3500		
3	Bed material	E	0.1	2	0.4	0.2	0.7	2.85	3	0.132		1	450
	Before test	A	8	10	54	2	0	0	0		260		
4	Bed material	E	0.2	5	4.5	0.9	2.2	7.84	3	0.034		1	2080
	After test	A	6	100	118	100	62	0	560		780		

Analysis method
E Eluat (24 h)
A Acidic breaking down

Table 13.7 Allocation to the landfill class according to (AbfAblV 1998)

Assignment to landfill class			Heavy metals [mg/l Eluat]							Rest-C	Landfill-
Pos.	Sample		Pb	Cd	Cr	Cu	Ni	Hg	Zn	[M%]	**Class**
	Limit/standard	**E**	**≤0.2**	**≤0.05**	**≤0.05**	**≤1**	**≤0.2**	**≤0.005**	**≤2**	**≤3 M%**	**1**
1	Cyclone ash	E	0.01	*1.80*	*0.24*	0.05	0.13	*0.88*	0.60	0.01	**2**
2	Cyclone ash	E	0.04	*1.40*	*1.40*	0.03	0.11	*0.08*	0.40	0.00	**2**
3	Bed v Test	E	0.01	*0.20*	0.04	0.02	0.07	*0.29*	0.30	0.13	**2**
4	Bed n Test	E	0.02	*0.50*	*0.45*	0.09	*0.22*	*0.78*	0.30	0.03	**2**

Italic values—exceeded limit landfill class 1 (AbfAblV 1998) residues and classify the ashes and the bed material of the BRAM sewage sludge incineration as a waste of landfill class 2.

13.5 Summary and Recommendations

In the experiment carried out, the process automation of the thermal sewage sludge disposal in a stationary fluidized bed furnace of low power was successfully tested by means of a temperature-controlled control. The experiment has shown that the NOx emissions of combustion of high dry residue sewage sludge require regulation. Also the HCl emissions are too high and require the adjustment of the ratio additive/chlorine.

Further emissions are technically easy to control and behave inconspicuously. This could be demonstrated using the example of SO_2 emission by adding limestone to the firing area. Previous tests with sewage sludge from Rostock (similar characteristics as the Syrian sludge) show that even after the sludge has been dewatered (TR = 30 M%), a low-emission combustion (Tmin = 850 °C) with sewage sludge contents of xKS = 75 M% of the mixed fuel possible is. Due to their pollutant content, the process residues of the process must be stored in class 2 landfills.

13.6 Recommendation of the Thermal Sewage Sludge Disposal Option in Syria

- When applying this procedure in another MENA region country, the regional characteristics must be taken into consideration.
- An integrated system to ensure the environmental and economic waste management is the subject of chapter. The waste material flows should be prepared, utilized and disposed of according to the physical and chemical properties.
- Based on the positive results of the presented investigations, a 6 MW SFBC steam power plant fueled with pre-screening material and/or fine screening material should give positive economic and environmental effects. The technical solution is innovative.
- In Syria, this applies above all to sewage sludge and residual waste as an auxiliary fuel.
- The untreated Syrian sewage sludge has a calorific value similar to the treated European sludge (anhydrous reference state, w = 0), as well as a slightly higher exposure to heavy industrial and commercial metals.
- An important aspect of the arid Syrian climate is the simple and cost-effective solar drying of sewage sludge to a dry residue of TR > 90 M%.

- For incineration of such dried sludge, the substitute fuel would not be necessary. Here, it has to be increased due to the concentration of pollutants, the cost of the flue gas treatment (primary/secondary).
- The residual Syrian waste composition generally has a higher native organic content (50–60 M%). Experiences with the substitute fuel production with this medium do not exist here.
- With regard to the population growth in Syria, the increasing level of connection to the public sewer system, as well as progressive reform efforts in politics and privatization of the economy, increasing amounts of sewage sludge with increasing burdens can be expected in the future.

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Chapter 14
Solid Waste Characterization and Recycling in Syrian Refugees Hosting Communities in Jordan

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Abstract It is undeniable that solid waste management in the Syrian refugees host communities was one of the most challenging services to be properly provided to the vulnerable communities by municipalities in Jordan. This paper presents the current waste generation and composition for both Irbid and Mafraq which are considered urban and rural areas, respectively, based on the urbanization index. Hence, the MSW composition in Irbid has relatively less organic content (51%) and more plastics (11%) and papers (12%) than that at Greater Mafraq (58% organics, 10% plastics, and 9% papers). On the other hand, the study reveals that the waste recycling (19%) and recovering (25%) in Mafraq Governorate are relatively much better than that in Irbid Governorate where waste recycling and recovering are 9 and 8%, respectively. The study presents a possible waste recycling model and opportunities to link the private waste-picking activities with the public SWM sector at the local municipality and dumpsite levels. A participatory model to create income generation potentials for the most vulnerable groups in the society (Jordanian Citizen and Syrian Refugees) is proposed based on the study findings.

Keywords MSW · Informal recyclers · Syrian refugees · Waste · Recycling · Jordan

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14.1 Introduction

Municipal solid waste (MSW) is a growing social and environmental concern nowadays for all countries developing from low-income to middle- and high-income levels. Urban waste management comprises nearly 20% of municipal budgets, on average, for many local administrations in low-income countries. Moreover, the waste generation per capita is projected to increase by 40% or more by 2050 in low- and middle-income countries [9]. The Middle East and North Africa regions are generating 6% of the world's waste, relatively the least in absolute terms according to the urban development series by World Bank Group (https://openknowledge.worldbank.org/handle/10986/2174).

Most of the MSW generated is disposed of in dumping sites (i.e., 93% of waste is dumped in low-income countries), causing severe pollution and overload of waste [9, 12, 14, 24, 26]. MSW should be appropriately disposed in order to help protect environmental quality and human health, as well as to preserve natural resources (Tchobanoglous et al. [14, 15, 21, 23, 26, 27]. In 2016, approximately 1.6 billion tonnes of carbon dioxide (CO_2) equivalent greenhouse gas emissions was generated from solid waste treatment and landfilling, and it is expected to increase to 2.6 billion tonnes of CO2-equivalent per year by 2050 if no additional improvement is made on business-as-usual scenario in the sector [9].

The municipal solid waste management (MSWM) services are no longer of the same standard as that prior to the massive influx of Syrian refugees into the Northern part of Jordan (Mafraq and Irbid Governorates) [1, 7]. The solid waste generation is expected to increase on account of development activities, population growth, and changing patterns of Jordanian consumption behavior by approximately 3%/year [2–5, 16–19]. Also, changes in public awareness can also be expected to affect it [22]. Moreover, the informal sector plays a vital role in SWM since it provides a livelihood to immigrants and refugees [6, 17].

According to UNHCR reporting and studies done in October 2014, when the total number of Syrians Refugees in Jordan had reached 650,000 at that time, the Syrians Refugees were equivalent to almost 10% of the Jordanian population.

As indicated in Fig. 14.1, the highest concentrations of the Syrian Refugees are in Northern and Central Jordan in October 2014; including Amman (27.7%), Irbid (23.3%), Mafraq (12.8%), and Zarqa (8.5%) JRPSC [8]. For example, Mafraq and Irbid Governorates have witnessed an influx of refugees equaling 57.8 and 12.5% of their total populations, respectively.

The MSW generation rates have dramatically increased during the last four years and posed a heavy burden on the local host communities with limited absorption capacities, such as Irbid, Mafraq, and Ramtha. It is reported that 649,000 tons of waste are currently being generated annually, collected, and subsequently hauled away by the municipalities to the relevant final disposal landfill sites. However, only 15% being recycled and recovered MoMa [11].

The objective of this chapter is to review the current waste generation and composition as well as to explore the existing waste recycling and materials recovery

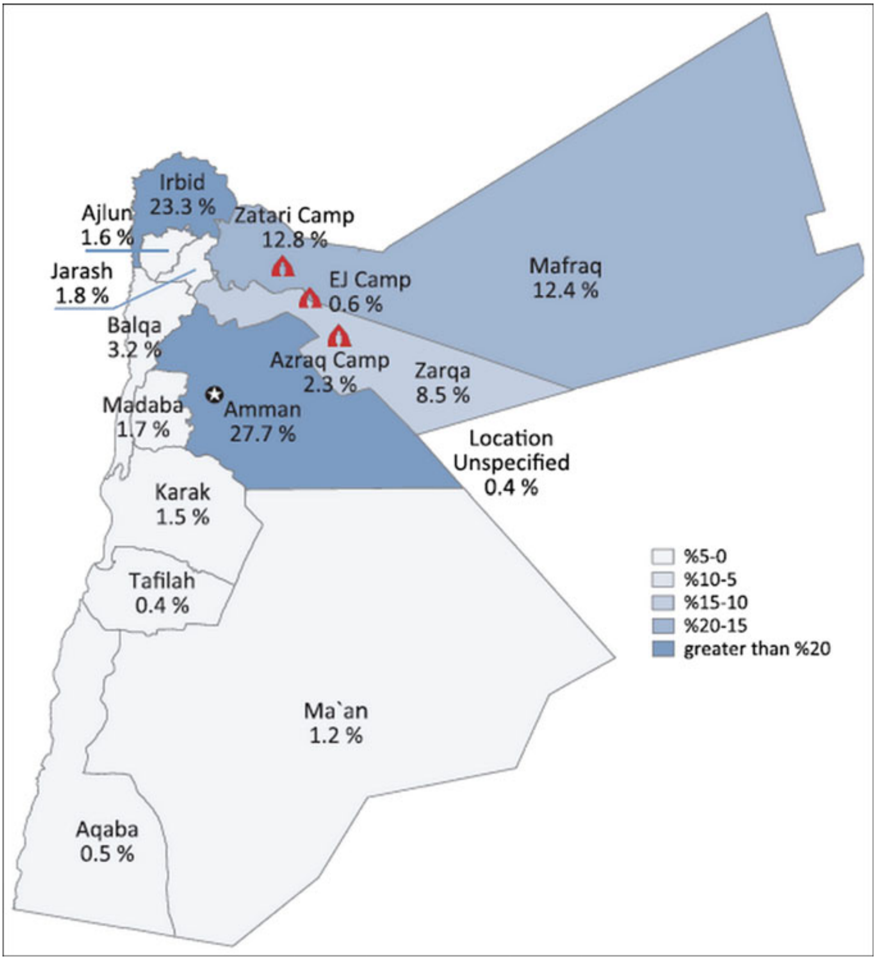

Fig. 14.1 Distribution of Syrian Refugees in Jordan per governorates in 2014 JRPSC [8]

activities in local municipalities of Irbid and Mafraq Governorates. Moreover, the present study aims at identifying the possible waste recycling model and opportunities to link the private waste-picking activities with the public SWM sector at the local municipality and regional dumpsite levels.

14.1.1 Institutional Framework

Although a new draft law on the management of waste is currently in its final phases to become Jordan's first separate contemporary waste management law that follows the international "polluter pays" principle, till now SWM legislation is practically non-existent at the national level. At the national level, the Government of Jordan has adopted strategies, which relate to the management of municipal solid waste. These strategies include the following:

- The Jordan 2025—A National Vision and Strategy;
- The recent National MSW Management Strategy (NMSWMS);
- The National Environmental Strategy;
- The National Energy Strategy; and
- The National Strategy on Public–Private Partnerships (PPP).

Although a dedicated SWM law has not yet been adopted, some legal provisions pertaining to SWM are included in other laws. These laws include the following:

- Municipalities Law No. 41 (2015);
- The Joint Services Councils Regulation No. 113 (2016);
- The Regulation for Nuisance Prevention and Waste Collection Fees within Municipal Borders No. 68 (2016);
- The Supplies, Purchases and Civil Works for Municipalities Regulation No. 70/2009 and its Amendment Regulations No. 34/2015 and No. 4/2016;
- Environmental Protection Law No. 52 (2006), which is in the process of updating by a new one;
- Solid Waste Management Regulation No. 27 (2005);
- Instructions for the Management of Solid Waste (2006);
- Hazardous Waste Handling and Management Instructions (2003);
- The Regulation for Protecting the Environment from Pollution Emergency Situations No. 26 (2005);
- Renewable Energy and Energy Efficiency Law No. 13 (2012);
- The Environmental Impact Assessment (EIA) Regulation No. 37/2005, and;
- Waste Oil Handling and Management Instructions (2003).

The above laws do not comprehensively address the issue of municipal solid waste management. The Management of Solid Waste Regulations No. (27) of 2005,[1] for instance, only list the (five) duties of the Ministry of Environment in SWM and define the obligations of SWM actors and SW generators as follows:

A. Provide the qualified manpower resources for solid waste management and public safety measures for its workers.
B. Provide the vehicles, containers, and equipment needed for solid waste management.
C. Monitor the collection of solid waste and setting the route thereof and transportation thereof to locations designated for disposal thereof.
D. Place containers in the appropriate locations and maintain them and replace them when destroyed.
E. Take the measures necessary to prevent hazardous waste reaching solid waste containers and transportation means.

[1] http://moenv.gov.jo/En/Pages/Policy_ar.aspx.

F. Keep regular records in which are listed the quantities and sources of solid waste, and the methods of treatment thereof, and the vehicles operating in this field.
G. Supervise sorting, excavation, and landfill activities, and monitoring the compliance with the stipulations appearing in solid waste management contractors' contracts.
H. Forbid the burning of solid waste or the disposal thereof in an exposed manner.

The management of solid waste in Jordan is therefore mainly governed by local regulations of which By-law 150 of the year 2016, titled Nuisance Prevention and Waste Collection Fees, is the most important. The regulation states the role and responsibility of municipalities to obtain fees for the collection, transportation, disposal, and treatment of SW. Also, it regulates the activity within the borders of municipalities regarding any nuisance to health and the environment. Moreover, the regulation stipulates the fees for SW collection by municipalities for (a) residential units (depending on their electricity consumption), (b) commercial and industrial units, and (c) others, depending on size, type, and quantity of SW generated from any facility. It is noted that there are specific instructions of fees for the collection, transportation, disposal, and treatment of SW (2014) used by municipalities to estimate these fees according to certain categories and conditions.

Regulation 150/2016 constitutes the update of the Regulation No. 83/2009, according to the Article 6 of the Municipality Law 41/2015 and includes updated instructions for (1) waste collection, (2) transfer, (3) treatment, (4) and disposal.

The by-law states that (1) waste collection, (2) transfer, (3) treatment, (4) and disposal will be carried out by municipalities' staff within the relevant departments. Nuisance prevention and the application of penalties and fines will be carried out by municipalities' staff—giving the staff the status of law enforcement official authorized to impose fines.

The Nuisance Prevention and Waste Collection Fees by-law article 10/A also concerns the collection and transfer of waste. The by-law states that any individual or entity does not have a right to handle waste without written approval from the mayor. The by-law also sets the financial fines that will be imposed if written approval is not obtained. Additionally, Article 15 gives health inspectors the authority of law enforcement regarding waste collection and places them under the judiciary.

14.2 Materials and Methods

14.2.1 Study Area

This chapter focused on two governorates in the northern part of Jordan: Irbid and Mafraq. Governorate of Irbid constituted of nine administrative districts and 18 local municipalities, lies next to the Syrian border. The Governorate of Mafraq lies next to the Syrian border and Iraq and has four administrative districts and 18 municipalities and a very low population density.

Table 14.1 Population data in Irbid, Ramtha, and Mafraq municipalities

Population	Municipality		
	Irbid	Ramtha	Mafraq
Jordanians	523,352	96,269	81,000
Refugees	98,700	62,700	99,000
Total	622,052	158,969	180,000

There is heightened pressure on the local municipalities to deliver more and better municipal and social services due to the remarkable increase in population in Irbid, Ramtha, and Mafraq municipalities, as shown in Table 14.1.

The current final MSW disposal site where the daily MSW deliveries disposed of in Irbid Governorate (Al-Akaider) is managed at the regional level by Joint Service Council (JSC) Irbid, and the same for Mafraq Governorate; where the daily MSW deliveries disposed of in (Al Ehsyniat) which managed by JSC Mafraq. The JSCs are in charge of the daily MSW disposal operations being done at the landfills.

The Al-Akaider site is located 35 km East of Irbid and 15 km East of Ramtha in Mafraq Governorate. The site was established in 1983. It covers in total 90 ha; the tipping area for solid waste is approximately 32 ha. The height is at its maximum 30 m. Depending on different parts of the site the total height can be increased further, which results in remaining airspace of 1.5–2.5 million m^3. JSC reports daily waste delivery of 1200 tone. Al-Akaider currently serves nine municipalities in Irbid Governorate and other five Municipalities in Jerash and Ajloun Governorates.

The Al Ehsyniat disposal site is located 20 km East of Mafraq and covers 38 ha with a current tipping area of 18 ha. According to JSC, the site receives 200–250 t/day, while it was 100 t/day before the Syrian crisis. Al Ehsyniat site currently serves 10 municipalities in Mafraq Governorate, in addition to the Za'atri Syrian refugees camp located in Mafraq. The Al Ehsyniat site provides sufficient airspace for at least another 10 years, even with the rapidly increased amount of waste for disposal.

14.2.2 Methodology

To carry out such investigations, semi-structured interviews, intensive consultations, and site visits were conducted with the relevant stakeholders to review the current waste generation and composition, as well as, explore the existing material recovery actions in local municipalities of Irbid and Mafraq.

During this research study, meetings have been conducted with key stakeholders: the Municipality Irbid and Greater Mafraq; the JSC of Irbid Governorate and Mafraq Governorate; and international agencies such as OXFAM, UNDP, and GIZ. This is to identify the opportunities of the recycling project in host communities that might be implemented (or to be implemented) by the international agencies and engagement of Syrians in the fields of MSW management.

The waste composition in each designated municipality has been analyzed on desk research basis. The research also includes socioeconomic assessment of the waste-picking activities in the North of Jordan.

Information obtained through the interviews was cross-checked with the objective to reassess the gaps and divergences of information. Reassessment questions were based on issues of divergences.

14.3 Results and Discussions

14.3.1 Urbanization Index of the Targeted Municipalities

The local populations of each municipality are usually distributed in urban and rural areas or districts, and this distribution should be considered in calculating the daily MSW generation rate per capita. Indeed, the percentage of the urban population within the municipal boundaries of Greater Irbid and New Ramtha municipalities in 2014 was 83%, while the urban population in Greater Mafraq was around 40%, as well as the rural population of Greater Irbid, and New Ramtha in 2014 was 17% and in Greater Mafraq was around 60% MoMA [11]. According to the index of the urban and rural distribution of the population, Greater Irbid and New-Al-Ramtha municipalities can be considered as urban areas, while Greater Mafraq is almost a rural area. Accordingly, it is assumed that the local municipalities Greater Irbid and New Ramtha have a higher urbanization index (75–100%), while Greater Mafraq has a lower urbanization index (0–50%).

14.3.2 Waste Generation and Composition

The availability of accurate baseline data and current MSW characterization with future projections concerning the population growth and MSW generation trends is vital to develop the MSWM system. The National MSWM strategy in Jordan has assumed that the population growth rate for years 2013 and 2014 of 2.22%, which is equal to the average values of the 2009–2012 periods. Since 2021, the population growth rate is expected to be 1.95% till 2039. However, 82.9% of the local population in Irbid Governorate is urban, and 17.1% is rural according to estimations of the National SWM strategy. For the Syrian refugees, the strategy assumed a 1% annual growth rate between 2014 till 2020 and assumed zero annual growth rate at 2025. Figure 14.2 shows the future projections (2014–2024) for the resident population in the targeted municipalities.

The MSW is generated by the commercial sector is assumed for the future projections, just over 20% of the entire domestic MSW quantities.

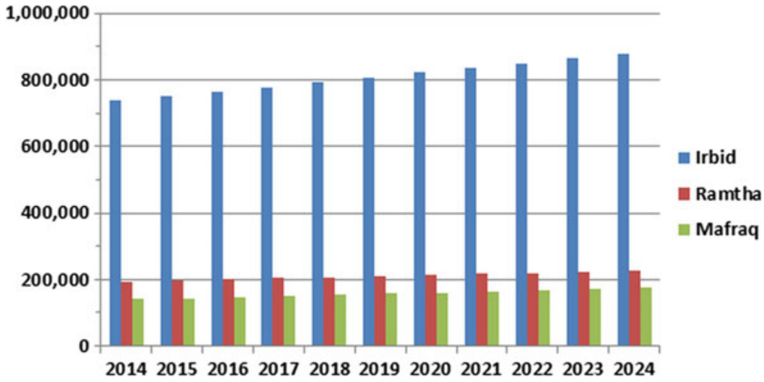

Fig. 14.2 Future projections (2014–2024) for the resident population in the targeted municipalities

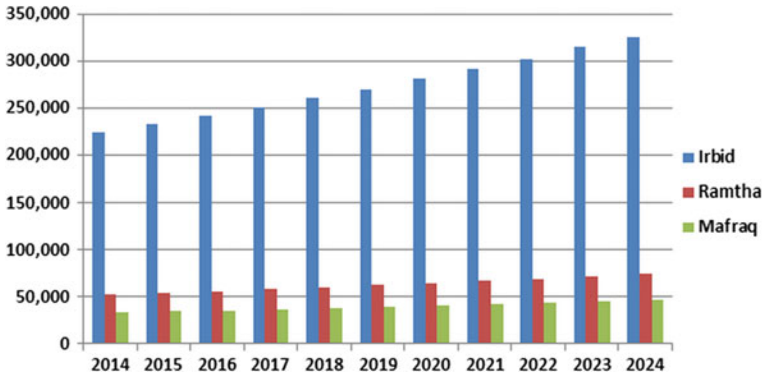

Fig. 14.3 Current and future (2014–2025) MSW generations (tons/year) in the governorates

The evolution of per capita MSW generation rate in Jordan during 2012–2039 has been proposed in the National MSWM Strategy, where the MSW generation rate in Jordan is assumed to reach about 1.64 kg/cap/day in urban areas and about 1.12 kg/cap/day by 2039 MoMA [11]. Figure 14.3 shows the current and future MSW generations (tons/year) in the governorates of Irbid, Ramtha, and Mafraq due to household residents by District, 2014–2025.

The MSW composition by governorates is shown in Fig. 14.4a, b, according to governorates' urbanization index, which is proposed in the National MSWM Strategy. This means that the MSW composition in Irbid and Ramtha might have less organic content and more plastics and papers. However, the MSW composition at Greater Mafraq might have more organics and fewer plastics and papers.

Accordingly, it is concluded that the assumed values for the plastics and papers composition to be used in the design for Irbid and Ramtha shall be 11 and 12%, respectively (at the worst scenarios) to be in line with the measured figures in the presented studies above. Where the shares of plastics and papers composition in

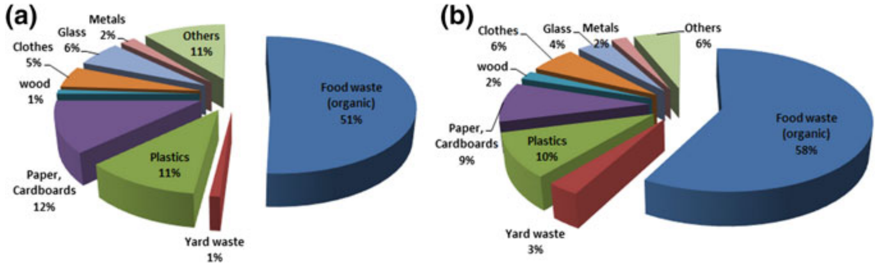

Fig. 14.4 Proposed MSW composition at the designated local municipalities: **a** Irbid and Ramtha, **b** Mafraq

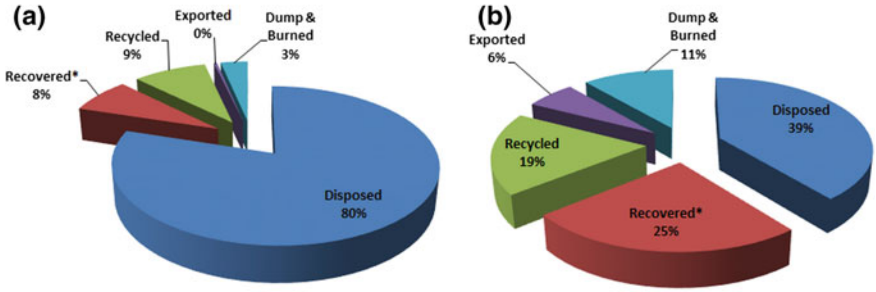

Fig. 14.5 Material flow of waste at the designated local municipalities: **a** Irbid and Ramtha, **b** Mafraq

Greater Mafraq do not exceed 10–9%, as well as, the share of the organics is more than 50%.

The material flow of waste discharged in both Irbid and Mafraq Governorates is shown in Fig. 14.5a, b. The data collected from a survey carried out among all stakeholders in the waste management chain. In this illustration (Fig. 14.5), it can be seen that the waste recycling and recovering are 9 and 8%, respectively, in Irbid Governorate. However, in Mafraq Governorate, the waste recycling (19%) and recovering (25%) are relatively much better than that in Irbid Governorate. The percentages are on the basis of the generated waste. However, a negligible percentage (less than 1%) of the recycled and recovered waste is exported in Irbid, while the exported waste in Mafraq is 6% of the generated waste.

14.3.3 Solid Waste Recycling

Many formal companies process scrap metal and plastics into post-consumer recycled material registered as manufacturers, thus not appearing in the registry as recyclers. According to the Jordan Chamber of Industry database, over 200 recycling businesses are registered in Jordan. However, this does not fully reflect the extent of the recycling sector. Remarkably, 66% of these recycling businesses were registered in 2011 due to the expanding waste generation and the waste valorization activities caused by the Syrian refugees. However, there are only five and six registered recycling companies in Irbid and Mafraq, respectively. Most of these companies are considered as scrap or waste brokering operations since they provide little or no processing of the recovered materials.

On the other hand, the informal waste picking flourishes both in the city streets and in the dumpsites level to sort out quantities of waste in order to produce personal income MoMA [11]. However, in the city streets, there are over 100 and 1000 street waste pickers are in Irbid and Mafraq cities, respectively, while the majority of whom are Syrian refugees. While in the dumpsites level there are up to 50 and 30 waste pickers in both of Al Ehsyniat and Al Akaider dumpsites, respectively. In between these two extremes, there are itinerant scrap collectors with trolleys or trucks, small and medium scrap dealers, generalist and specialized waste brokers. There are over 1000 such informal businesses in the Mafraq and Irbid Governorates.

The UNDP has reported that the total number of formal and informal waste actors engaged in the waste economy of Irbid and Mafraq municipalities is over 4000 workers of which 12% are female [25].

14.3.4 MSW Recycling Approach

The participation of the local Jordanian private sector in the different working fields of SWM is still limited and very modestly explored. Almost all MSW recycling activities in Jordan, present and past, are considered pilot projects and small-scale interventions, which are mostly initiated and supported by the NGOs and other international organizations. Moreover, the informal waste recycling sector has developed over the last twenty years due to the absence of national formal recycling systems.

In May 2015, a new national strategy for MSWM was launched, and it recommends mitigating the informal waste picking of MSW through integration into the MSWM system including the establishment of partnerships between the public and the private sectors. The provision of better MSWM services for the affected host communities should consider the engagement of both Jordanian citizens and Syrian refugees who can sustain any resilience actions targeting the improvement of livelihood for them.

Stakeholders' consultation should be a top priority for policymaking and governmental decision considering the waste recycling business in Jordan. As described by Scheinberg et al. [20], the classification of stakeholders into providers, beneficiaries, and external agencies is used here to present the different stakeholders, roles and responsibilities, and their inter-linkages in the SWM system.

In this context and in light of the organizational set-up of the SWM system suggested by Lohri et al. [10], the SWM recycling model for Syrian refugees hosting communities in Jordan can be represented by Fig. 14.6. This consequently enables

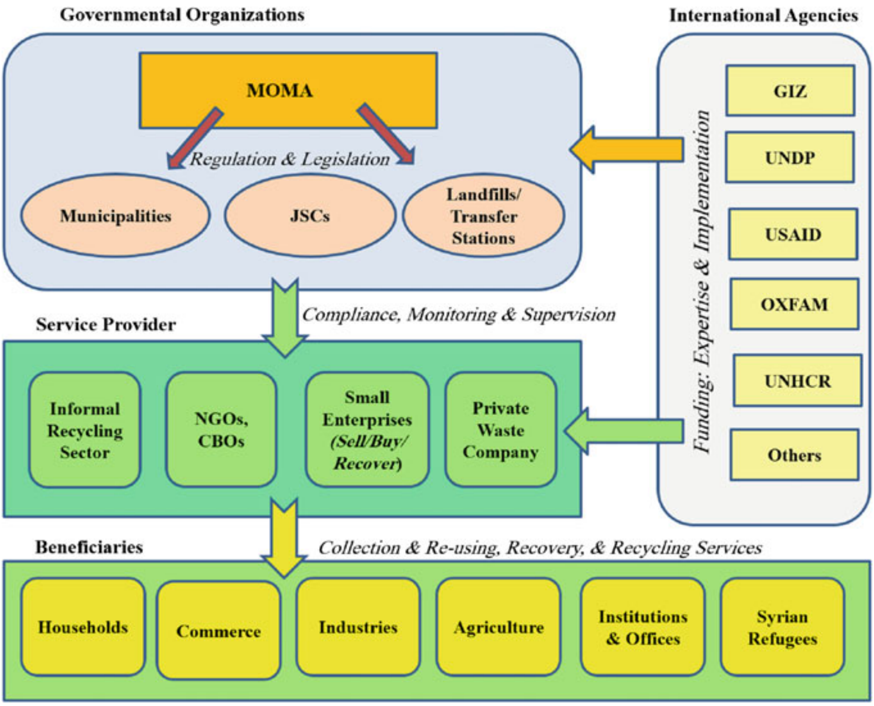

Fig. 14.6 SWM recycling model for Syrian refugees hosting communities in Jordan [10]

in return the determination of the stakeholders' influence (the extent to which their decision, power or persuasion can achieve a relevant course of action/change) and interest (the extent to which the issue is a priority for them, as well as, their willingness, readiness, and responsive attitudes). Arrows depict either regulatory or legal functions (e.g. national regulation and legislation), different service functions (waste collection, recycling, etc.), and/or support functions (financial, knowledge and expertise) [10].

The main focus of such recycling approach is the development of a participatory system to establish labor-intensive material recovery and processing systems to create income generation potentials for the most vulnerable groups of the society (Jordanian citizen and Syrian refugees). Eventually, these participatory initiatives reduce conflicts between Jordanian citizens and Syrian refugees through a joint involvement of both groups in waste recycling activities of the massively littered environment.

In the Syrian refugees hosting municipalities, several MSW recycling and reuse options can be proposed. However, the organizational model of the SWM recycling system, as shown in Fig. 14.6 can be differentiated on a case-by-case basis to fit the purpose of the proposed option. The effectiveness and sustainability of the proposed organizational model of the SWM recycling system depend upon their adaptation to the prevailing context of the governorate and/or municipality in which they operate.

14.4 Conclusions

Municipal services, particularly in the northern governorates of Jordan, have been stretched by over-populated host communities leading to increasing societal tensions and raising pressure on livelihoods which is the main current threat to social cohesion. This study was carried out to addresses essential findings that influence the viability of various parameters and approaches to resource recovery, recycling, and reuse. The current rate of solid waste generation in Irbid and Mafraq is a combined 649,000 tons annually with approximately 85% of this waste is currently being disposed of at landfills or by uncontrolled dumping, while the remaining 15% is recycled and recovered. There is thus a significant scope to increase the level of recycling and recovery for the solid waste in both governorates. There is a need to establish labor incentive material recovery based on the participatory model to create income generation potentials for the most vulnerable groups in the society (Jordanian Citizen and Syrian Refugees).

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Chapter 15
Innovation Technologies in Wastewater Treatment: A Cost-Effective Solution—Jordan Case Study

Noama Shareef

Abstract Natural and semi-natural wastewater treatment system is used in the rural area, to protect the environment and to improve the treatment efficiency processes in the wastewater treatment units and reuse it in agriculture as low-cost treatment solutions especially in water scarcity countries like Jordan. Different wastewater technologies are commercially used for the treatment of municipal as well as industrial wastewater. Wetland technologies, SBR, septic tank, modified septic tank, and biofilm system are successfully implemented in Jordan in the one of an important demonstration research center and also in several cities in Jordan. Decentralized wastewater treatment processes were achieved by the aeration in aerobic systems (oxidation of organic compounds and nitrification) and wetlands system. The aim of this chapter is to demonstrate developing and transferring some innovative wastewater technologies as an example in Jordan Valley as an approach for integrated water resources management (IWRM). This was implemented by several international supports to enable sustainable use of water resources. Also to demonstrate **S**ustainable **M**anagement of **A**vailable Water **R**esources with Innovative **T**echnologies (SMART) treatment efficiency of some innovative treatment technologies of municipal wastewater in small scale and reuse it for irrigation purpose. Furthermore, it is necessary to insure the local water quality required, a cost-effective treatment, sustainability, and protection of public health. The development and adaptation of the above technologies and solutions have considered the local conditions and climate change.

Keywords Small scale · Wastewater treatment · Biological · SBR · Wetland · Nitrification · IWRM

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15.1 Introduction

Jordan is located in a semi-arid climatic region, characterized by extremely dry conditions. It is considered as one of the regions with the highest water scarcity in the world, with annual precipitation of about 150 mm and potential evaporation rates of 2600 mm per year [1]. This situation combined with the increase of water demand for household consumption and agriculture due to population growth and the pollution of available water sources with wastewater represents a challenging situation for the management of the water resources. Furthermore, just around 63% of its populations are connected to a sewer system in 2014 and producing about 137 MCM of the effluent/year [2]. On the other hand, about 93% of the people who lives in the rural areas are utilizing cesspools as mean sanitation. About 51% of 2014 water was utilized for irrigation including the treated wastewater. Irrigation by fresh water only used 381 MCM forming only 45% of freshwater [3]. While 61% of the available water resources are used for irrigation purposes. Groundwater levels have dramatically declined to verify that groundwater exploitation has been unsustainable, further aggravated by erratic rainfall. Given its high population growth rate and the factors mentioned before, the impacts of climate change put enormous additional pressure on the management of Jordan's water resource as a whole [4]. Putting Jordan in the category of having an absolute water shortage, this will likely constrain economic growth and potentially endanger public health. This already severe water stress is expected to be exacerbated by climate change as a result of projected decreases in precipitation and shifts in its spatial and temporal distribution.

Water management in Jordan, as in many other parts of the world despite significant improvements in the corresponding infrastructure, a critical supply–demand imbalance remains. Small-scale, decentralized and mainly demand-focused measures on the other side, i.e., decentralized wastewater management, long-term and comprehensive loss reduction measures, rainwater harvesting, aquifer storage and the use of renewable energy in water supply are widely discussed, and its potential added value acknowledged; however, they receive relatively less attention when it comes to concrete implementation [5].

15.2 Overview—IWRM Projects in Jordan and Short Description of Some Projects Activities in the Region

During the last some years, several pollution reduction projects have been identified by the countries around the southern and eastern parts of the Mediterranean Sea. Those projects were part of the countries' National Action Plans and/or part of a national strategy developed to address land-based pollution sources affecting the Mediterranean Sea from three main sectors: wastewater, solid waste, and industrial emissions [6]. These investment projects have all been subject to some kind of progress since their inception. Some of them have secured financing and by doing so are either completed or under implementation. Others have not yet secured financing and are either pending or under preparation through feasibility studies and loan negotiations. Therefore, to create an alternative water resource in Jordan, several European organizations supported the transformation and implementation of wastewater innovate technologies in small scale as decentralized treatment system like but not limited to the following projects.

15.2.1 SWIM Project

SWIM is a regional technical support program that includes the several partners' countries. The program was funded by the European Neighborhood, to promote actively the extensive dissemination of sustainable water management policies and practices in the region given the context of increase of population, especially on the coast and in large cities in Southern countries, increasing water scarcity, combined pressure on water resources from a wide range of users, and desertification processes, in connection with climate change,and it was implemented several small wastewater treatment plants as pilot projects in partner countries in the region to be successful case studies [7].

15.2.2 NICE[1] Project

NICE Project is National Implementation Committee for Effective Integrated Wastewater Management in Jordan. This project is supported by the German Ministry of Education and Research (BMBF). The project's aim is to protect water resources in Jordan and provide the small and rural areas with several wastewater treatment technologies and insure the treated water quality and reuse it in irrigation with respect to Jordanian standards for reuse.

All project activities and plans are done in cooperation with water sector in Jordan and with several local stakeholders for serious concerns of water scarcity, water resources protection, considering several social, technical, and economic factors.

This leads to put the potential decentralized wastewater management and reuse in the national water strategies in Jordan. This was needed to develop the sector effectively and to insure its sustainable service.

The project phase 2 is ongoing in the present time to develop a framework of certification system for decentralized wastewater treatment system for operation and maintenance, marketing strategy for DWWM, to support Jordan in some emergency plan for wastewater management in refugee camps places, applying the integrated

[1] http://www.datacite.org/.

wastewater management concepts and the implementation of the reuse target for Jordan according to the (SDG 6) goal, furthermore, support the SMART move project in Jordan.

15.2.3 SMART[2] Research Project

Sustainable Management of Available Water Resources with Innovative Technologies. The implementation aim of this project was to improve the integrated water resources management (IWRM) and technology transfer of several innovate wastewater treatment technologies in adaption with climate change with respect to local conditions and standards. The main part of this project goal is to support the capacity developing activities and technical solutions which were developed within the project by the partner countries in the MENA region.

Development activities have been part of the strategy for achieving a successful adoption of the information and system solutions developed within the project by the partner countries. In the implementation phase, the CD activities play an even more relevant role for accomplishing the objective of transferring innovative technologies and management instruments. This project was supported by UFZ-Germany [8].

15.2.4 ACC[3] Project

The project "Decentralised Wastewater Management for Adaptation to Climate Change in Jordan (ACC)" is a bilateral project which started in July 2014 to support Jordan in developing its capacity to react to climate change and its impact on the water sector.

The first phase of this project was the commissioning of a study which analyzed the potential for decentralized wastewater treatment plants (DWWTP) in Jordan in order to identify promising locations suitable for piloting the application of DWWM.

The activities in all the above projects addressed a set of challenges faced by rural populations regarding (non-conventional) water resources (including soil erosion, rainwater harvesting, wastewater management, etc.). The focus on the ecological sanitation concept included rainwater harvesting, production of energy and artificial soil, urine separation, anaerobic wastewater treatment (upward flow anaerobic sludge blanket (UASB)), implementing of several wastewater technologies like SBR, septic tank, reed bed sludge treatment, activated sludge system, gray wastewater treatment, and constructed wetlands.

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[2] See Footnote 1.

[3] http://www.dwm-acc-jordan.net/decentralized-wastewater-management/the-challenge/.

15.3 Successful Case Studies—SMART Facility—Jordan

15.3.1 Materials and Methods

Discerption of SMART Facility: A facility was constructed in 2009 at the sewage treatment plant for the villages of Al-Fuheis and Maheis, for the research, demonstration, and training in the field of decentralized wastewater treatment and treated wastewater reuse in agriculture purposes (see Fig. 15.1).

It is located approximately 17 km away from Amman, the capital city of Jordan. The annual average precipitation in the region is of approximately 280 mm, with precipitations events principally from November to April. The summer temperatures reach temperatures of 30 °C prevailing from May to October [10].

This facility accommodates various decentralized wastewater treatment technologies (two different Vertical Flow Constructed Wetlands Technologies VFCW, two modified septic tanks, sequencing batch reactor SBR, continuous batch reactor, membrane bioreactor, and sludge dewatering reed bed. The site also contains three irrigation fields (plots), as depicted where reuse of treated wastewater in irrigation can be tested. Inflow wastewater into all WWT-plants is provided directly from the centralized municipal wastewater treatment plant for Fuhais & Mahis, (which located very close to the demonstration facility), after screening without pretreatment into collection tank at the demonstration site. The inflow for each technology is controlled by several electromagnetic flowmeters and the treated effluent from each technology is controlled/collected in a separate tank to check its quality. Even the treated wastewater meets the Jordanian national standards for treated wastewater reuse in irrigation JS 893/2006; it pumped back to the municipal wastewater treatment plant without reusing it. Currently, there are ongoing projects and implementation plans to use it in irrigation. The facility is equipped with an on-site laboratory where most of the

Fig. 15.1 SMART-Research, training and demonstration Center for decentralized wastewater treatment technologies and reuse in Jordan [9]

water quality analyses are conducted; the laboratory at Al-Balqa Applied University was used to control water quality of the facility, as it is a local partner for this project and hosted all its activities.

15.3.2 Short Description of Several Technologies from SMART Site

15.3.2.1 Sequencing Batch Reactor (SBR)

The SBR Pilot plant is constructed at the demonstration side (Fig. 15.2), as wastewater treatment unit. The system sequencing batch reactor (SBR) is used normally to treat industrial and municipal wastewater by activated sludge technology. The project aims to demonstrate these wastewater treatment systems: socio-economically, environmentally feasible and can complement as centralized wastewater treatment. Three sequencing batch reactors (SBRs) were installed in parallel with other technologies. ATB Environmental Technologies Ltd. supplied three plants as commercially available add-on kit; a conventional SBR plant, an SBR with UV light, and a so-called continuous batch reactor (CBR). These add-on kits were fitted as a single component in each tank as shown in Fig. 15.2. The SBR system at SMART facility site consists of two compartments; the first one receives raw wastewater from the inlet tank without pretreatment and used as a preliminary treatment unit in which pretreatment processes occur. The second compartment receives the preliminary treated wastewater and is considered as a secondary treatment unit, in which all biological treatment processes occur.

The german Company ATB has been installed SBR technology (continuous batch reactor) at the Facility SMART site in Jordan. This technology was designed for high

Fig. 15.2 Schematic of SBR with UV light and SBR under operation [11]

treatment efficiency and low energy consumption. This system can be applied for several small-scale levels [11].

15.3.2.2 Multistage Single-Pass Vertical Filter

Vertical wetlands systems have been used widely for municipal and industrial wastewater treatment in several Europe countries and the USA since long time to produce a high water quality by several water treatments levels [12]. The system was implemented at the facility site-SMART and designed as low-cost wastewater treatment system by low energy consumption. The system here receives its inflow from the septic tank (pretreatment stage) by gravity as no pumping is required. This system was designed to be able to treat 3.4 m^3/day (approx. 40 persons). It consists of a septic tank as (primary treatment), first stage vertical wetland system (secondary treatment and nitrification), organic denitrification reactor (removal of nitrate), and a second stage vertical filter (pathogen reduction and further polishing).

To check the effect of the performance and water balance, the vertical filters were tested with and without wetland plants to check and test the effect [13, 14].

The treated wastewater has high-quality effluent and meets the Jordanian Standard for safe reuse (Fig. 15.3).

15.3.2.3 Recirculating Vertical Construction Filter System

Vertical construction filter systems are designed to produce a high-quality effluent within a relatively small footprint. The above design starts with the first stage of a septic tank for pretreatment followed by a recirculation tank. The effluent of recirculation is pumped onto the vertical filter. The effluent is returned to the recirculation tank while the rest leaves the system and is used for irrigation. The system is designed

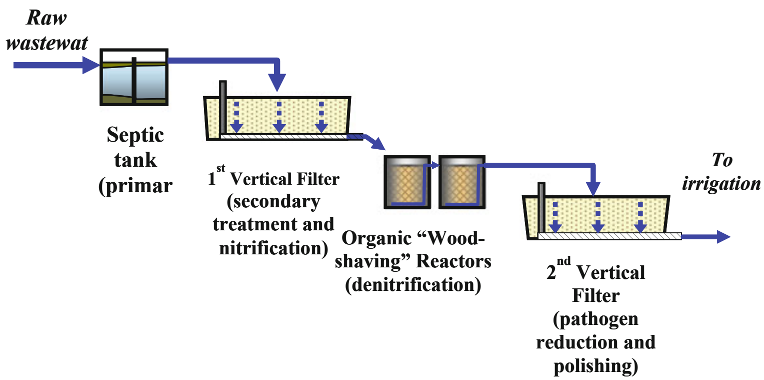

Fig. 15.3 Schematic of multistage single-pass vertical filter at the facility site [13, 14]

to treat 2000 L/day (approx. 27 PE). Wastewater is pumped into the upper surface of the vertical filter in small pulses and percolates downward toward a series of drainage pipes. Schematic profile of a recirculating vertical filter system is shown in Fig. 15.4 [15].

A portion (50–85%) of the water leaving the vertical filter is returned to the front end of the recirculation tank where it mixes with the septic tank effluent which is anaerobic and rich in organic matter as carbon resource which is needed for anaerobic phase. This provides the conditions required for the denitrification process (conversion of nitrate NO_3 into nitrogen gas). Recirculation also improves the performance stability by buffering flow peaks and diluting shock loads of contaminant [15].

15.3.2.4 French Wetland Systems

For applying recommendation of t is to accept raw sewage directly onto the first stage allowing for easier sludge management in comparison to dealing with primary sludge from an Imhoff settling/digesting tank. By using this system, developed by Cemagref more than 20 years ago. The system has gained a good reputation for small community wastewater treatment. Nowadays, it is well developed and several companies operate it. The sizing of such a system is rather empirical, based on the knowledge gained by Cemagref over years of laboratory studies and have been full-scale experiments on attached growth culture. The sizing of the reed bed filters is based on an acceptable organic load expressed as a filter surface unity per (PE). French system has been planned to operate as on vertical flow constructed wetlands for organic matter removal and nitrification and make easy the sludge management see Fig. 15.5. The principle of this “French System” is that it receives raw wastewater directly onto the first stage and treats the primary sludge on the surface of the first stage beds.

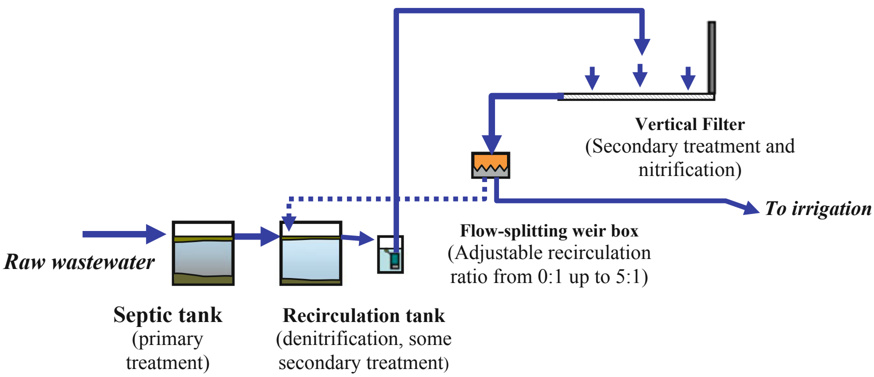

Fig. 15.4 Schematic profile—recirculating vertical filter eco-tech system site

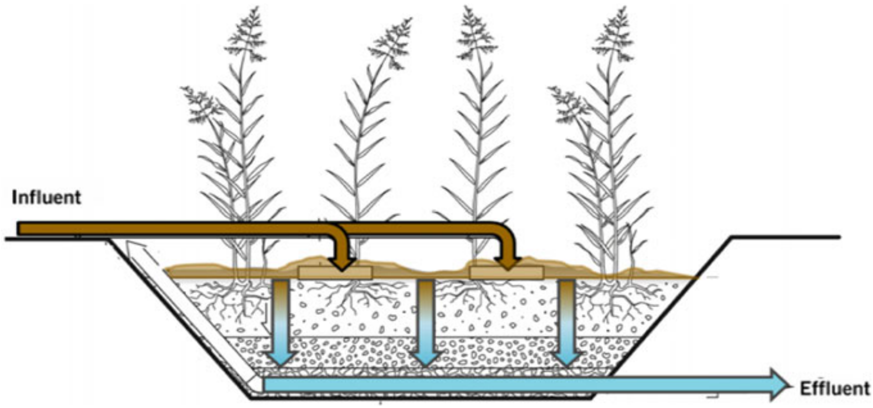

Fig. 15.5 French treatment wetland design, first stage only

At Fuheis site, French system was designed to operate in two stages: "French Wetland Stage 1" pretreatment and "French Wetland stage 2" for post-treatment. Each stage of the integrated sludge and wastewater treatment French wetland has parallel operated filter beds: under normal conditions 3 beds in the first stage and two beds at the second stage (1—French treatment wetland and 2—horizontal flow aerated treatment wetland).

The first stage of the French system receives raw wastewater without pretreatment direct from the collection tank. These alternating phases of feed and rest are fundamental in controlling the growth of the attached biomass on the filter media, to maintain aerobic conditions within the filter bed and to mineralize the organic deposits resulting from the SS, contained in the raw sewage which is retained on the surface of the primary stage filters. Then, effluent is sent to the second stage to complete treatment and, in particular, nitrification. The design surface depends on several factors but not limited to: organic load and requested wastewater treatment level.

A total area of 1.2 m^2 per PE, divided over three identical alternately fed units on the first stage (i.e., an organic load of <300 g COD/(m^2*d), <150 g SS/(m^2*d), <25–30 g TKN/(m^2*d), and a HL of 0.37 m/d on the filter in operation). In addition to 0.8 m^2 per PE divided over two identical alternately fed units for the second stage [11].

15.3.2.5 Modified Septic Tank Technology

The two modified septic tanks, suspended growth system, and attached growth system were designed to achieve anaerobic wastewater treatment, followed by aerobic wastewater treatment process, where treated water flows to the aerobic chamber by gravity for further treatment (low energy consumption). The modified septic tank with attached growth system (BA) is filled with fixed-bed media (plastic media-Biodeck). In both sections (anaerobic and aerobic), a fixed film (attached bacteria) was applied in order to increase the treatment efficiency and to test the treatment process under attached bacteria behavior in hot dry weather, see Fig. 15.6 [9].

The attached anaerobic/aerobic fixed-bed reactor with plastic sheets is working under biofilm system process. However, the septic tank prototype was divided into four chambers for anaerobic one followed by the aerobic chamber. The tow septic tanks were designed to treat domestic wastewater (household) with inflow capacity for each septic tank 1.2 m^3/day (10 PE-population equivalent).

15.3.2.6 Sludge Treatment Units

Because all above small wastewater treatment plants are in one place (Facility Al Fuhies site), reed bed sewage treatment is also built in the same place to treat the sludge of WWTPs in simple treatment methods. Reed beds sludge treatment technology is similar in design to subsurface-flow constructed wetlands (Figs. 15.7 and 15.8). The main difference is that sludge is applied on the surface and the filtrate flows through gravel to the underdrains. Typical beds are constructed of gravel 20 mm in diameter, 250 mm in depth, overlaid of filter sand of 0.3–0.6 mm. 10 years of accu-

Fig. 15.6 Modified septic tanks, suspended and attached growth system at the facility site

Fig. 15.7 Example of sludge loading, drying, and the final product

Fig. 15.8 Plant acclimatization phase in sludge drying beds during operation at Fuheis Facility site

mulation of sludge is possible if 1 m of freeboard above gravel layer is provided. Reeds can be planted on 300 mm centers in the gravel layer. See Fig. 15.7 [1].

Other vegetation can be used and first sludge application is possible after reeds are established. Winter is the time for harvesting to cut tops to a level above the blanket. Harvesting is requested if plant growth becomes too thick. Plants provide the pathway for continuous drainage of water from sludge layer.

Oxygen assists in the biological stabilization and mineralization of the sludge.

Table 15.1 Some wastewater treatment plants were built in small scale in Jordan was supported by NICE and SMART projects

WWTPs	IS	F	NH	HD	AA	MG	GH	MS	SH	AR
Type of technologies	Septic tank	SBR	SBR	Wetland	Wetland	MBBR	Modified septic tank	Modified septic tank	ASS	Wetland

A reed bed system is a form of passive composting. The design loading rates for reed beds are from 60 to 100 kg/m^2*year [16]. The typical sludge depth is 75–100 mm every week to 10 days (see Fig. 15.8).

Some other small wastewater treatment plants were installed in households' level scale and for small organizations were also supported by SMART to be as a pilot projects in the region which produces treated wastewater quality to meet the Jordan standards for irrigation purposes JS 893/2006 and [17] (Table 15.1).

This implementation of several technologies was not only for treatment and reuse purposes but also to use this successful WWTPs as regional research, demonstrating, training center to develop such technologies and using it as training places for several target group levels (students, public, national and regional engineers, farmers, and other stakeholders). Also to adapt the implemented treatment technologies according to a local condition in terms of climate change and very low water consumption in Jordan.

Utilizing treated wastewater for irrigation reduces the pressure on the fresh water resources, taking into consideration that the treated wastewater complies with the JS 893/2006 after [18]. Thus, utilizing reclaimed wastewater for irrigation purposes is becoming commendable and increasingly applicable in the agriculture sector in the country [19]. The presented technologies and also some others were designed to produce an effluent-treated water quality with respect to Jordanian standards for treated wastewater reuse for irrigation purposes JS 893/2006 after Jordan Institution for Standards and Metrology [18], see Table 15.2.

15.4 Results and Discussions

Wastewater treatment technologies in rural areas can be applied on all scales: household, small community, or complete neighborhood.

All presented technologies in this chapter show a high treatment efficiency in the reduction of several parameters but not limited to (BOD5 $\leq$ 15 mg/l, COD $\leq$ 100 mg/l, TSS: $\leq$ 25 mg/l, NH_4^-: $\leq$ 5 mgN/l, NO_3 $\leq$ 30 mgN/l) in most technologies. Similar treatment efficiency showed in some other wastewater treatment plants in small scales is installed in the Jordan by SMART, NICE, and SWIM projects.

This was in considering the highly organic raw wastewater concentration in Jordan because of low water consumption. 90 L/day per person [20], in comparison to European countries 150 L/day per person according to the OECD Development

Table 15.2 Jordanian standards for treated wastewater reuse in irrigation version JS 893/2006 after [18]

Parameter	Cooked vegetables, parks, playgrounds sides of roads within city limits	Fruit trees, sides of roads outside city, limits, landscape	Field crops industrial crops, forest, trees	Cut flowers
	A	B	C	D
BOD5 (mg/L)	30	200	300	15
COD (mg/L)	100	500	500	50
DO (mg/L)	>2	–	–	>2
TSS (mg/L)	50	150	150	15
pH	6–9	6–9	6–9	6–9
Turbidity (NTU)	10	–	–	5
NO_3-N (mg/L)	30	45	45	45
TN (mg/L)	45	70	70	70
E. coli (MPN/100 mL)	100	1000	–	<1.1
Intestinal Helminth eggs (egg/L)	< or =1	< or =1	< or =1	<1
Grease, oils and fats (mg/L)	8	8	8	8

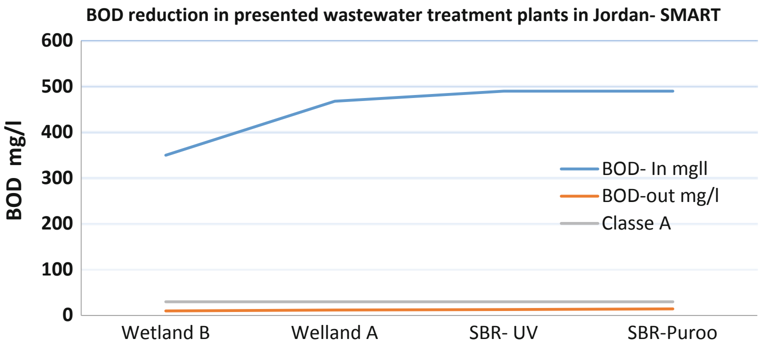

Fig. 15.9 BOD reduction in presented wastewater treatment plants at the facility site

Centre.[4] See Figs. 15.9, 15.10, 15.11, 15.12, 15.13, 15.14 and 15.15. These results were prepared to analyze one-year data from May 2015 to May 2016 as training tools prepared for internal and external training [21].

[4]See Footnote 1.

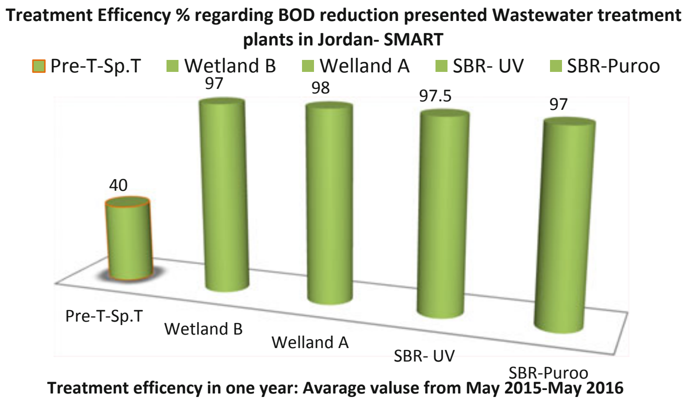

Fig. 15.10 Treatment efficiency of BOD reduction in wastewater treatment plants at the facility site

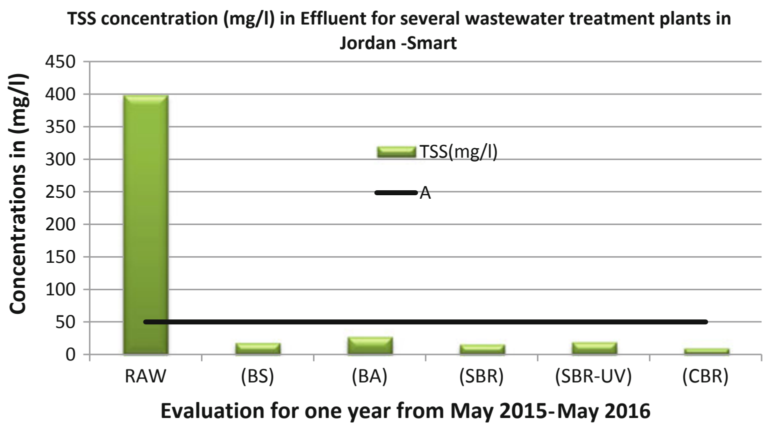

Fig. 15.11 Treatment Efficiency of TSS reduction in wastewater treatment plants at the facility site

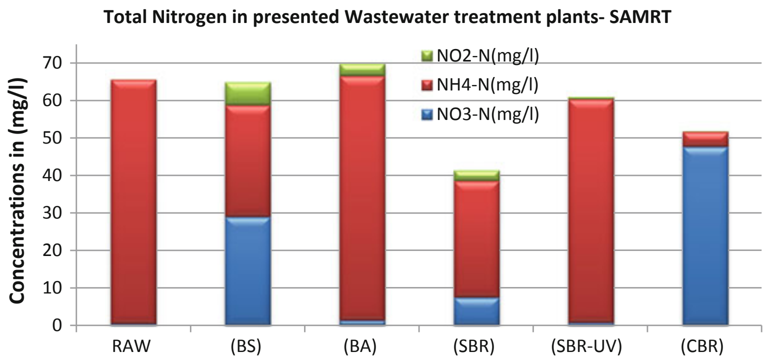

Fig. 15.12 Total nitrogen concentration in wastewater treatment plants at the facility site

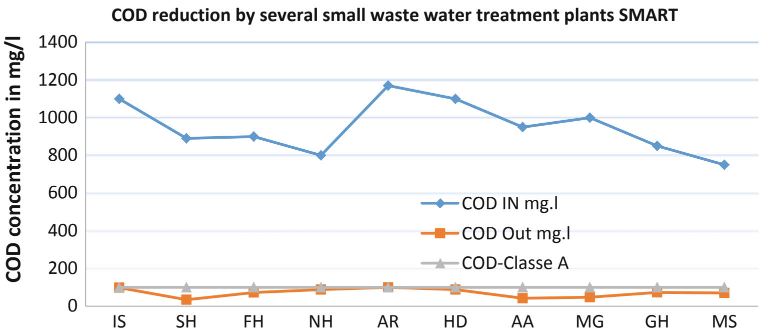

Fig. 15.13 COD reduction in small wastewater treatment plants at the facility site

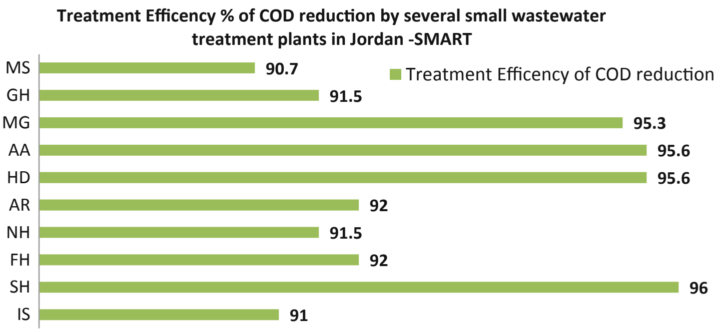

Fig. 15.14 Treatment efficiency for COD reduction in wastewater treatment plants at the facility site

Figures 15.9 and 15.10 show high treatment efficiency in BOD reduction, especially for the tow wetlands systems. VFCW systems were investigated considering category-A (TN: 45 mg/L and NO_3^-N: 30 mg/L) in the Jordanian Standards (JS) for reuse in irrigation (JS 893/2006). Recirculating and multistage VFCW designs have shown high removal efficiency of COD, TSS, and BOD5 over the one year from, May 2015 to May 2016, monitoring.

Also, the result for several wastewater treatment plants in household level shows a good efficiency treatment, and Fig. 15.15 shows that all small wastewater treatments in Jordan in Table 15.1 produce treated wastewater with NO_3 level in outlet less than class B after Jordanian standards for treated wastewater reuse in irrigation version JS 893/2006.

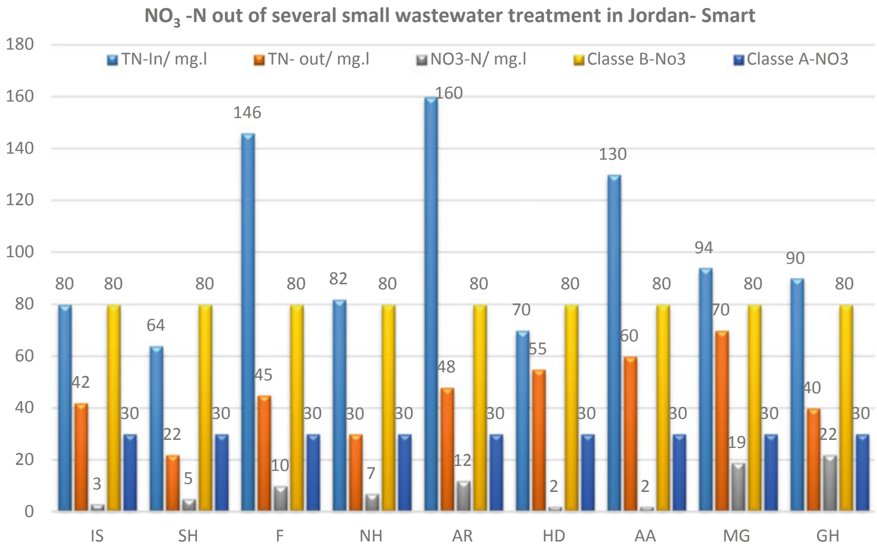

Fig. 15.15 TN reduction in small wastewater treatment plants at facility site

15.5 Conclusions

The evaluated wastewater treatment plants with a coverage analysis were met the Jordanian standards for wastewater reuse in irrigation version JS 893/2006. So this treated wastewater considers alternative water resources for irrigation because of implementation of several wastewater treatment technologies in decentralized level in one place and treated the same wastewater inflow, the location can be a good regional training modole to demonstrate the technologies and also developing researches related to application such technologies in the region.

Therefore, the applying of integrated water resources management (IWRM) has great potential to improve water scarcity situations in regions such as Jordan. These applications will help the decision-makers in political level, economical, social, cultural, and ecological sciences in addition to national and regional stakeholders contributing to IWRM processes.

Designing and implementing such wastewater treatment technologies will enable countries like Jordan to overcome the challenges related to water scarcity and climate change.

15.6 Recommendations

The authors highlight the following recommendations:

- Insure the sustainability of these technologies by supporting the local partner of these projects.
- Involvement in the national/local private sector in operation and maintenance to control and monitor the treatment efficiency of such treatment technologies
- Should take into account the social and cultural conditions, environmental and economic in the target area.
- Use the technology that is economically affordable, environmentally sustainable, and socially acceptable.
- The community should be able to operate and maintain such a simple system.
- The need for engagement private sector in order to exchange important experience and lessons in the sector of water and wastewater treatment in the MENA region.
- There is a need to involve all stakeholders in the policy dialogue, to implement strengthened standards for industrial wastewater discharge into sewage system (trade effluent)[5] and move toward the integrated water management Jordan.
- To achieve low-cost implementation and low energy consumption for small wastewater units in rural places, the local material has to be used during contraction and operation phases.

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[5]**Trade Effluent**: that is defined as any wastewater discharged to a sewerage system which is produced in the course of any industrial, commercial, agricultural, medical, and scientific or trade activity, but does not include domestic wastewater.

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Chapter 16
Biomass Waste in Yemen: Management and Challenges

Bilkis Zabara and Abdulbari A. Ahmad

Abstract The high output of biomass, which has increased during recent years, and the limitations of existing means of disposing biomass highlight the need to find alternative routes to manage this waste. The utilization of biomass as a renewable resource for energy recovery is the appropriate solution of how to manage the continuously increasing waste generation effectively in order to meet stringent environmental quality standards. In this chapter, an assessment of biomass resources, management and challenges will be presented. The broad areas of agricultural crop residues, urban wastes and animal wastes are included. The availability of these types of biomass together is given. A brief description of possible biomass conversion routes, sustainability measures, and current work and development activities in Yemen is provided. It is concluded that a large availability of biomass in Yemen gives a great potential for bio-fuel production from these biomass resources.

Keywords Biomass waste · Solid waste management · Biomass conversion · Wastewater management

16.1 Introduction

Biomass resources include wood wastes, agricultural crops, industrial waste and their waste by-products, municipal solid waste, animal wastes and wastes from food processing. "Globally, 140 billion metric tons of biomass wastes is generated every year from agriculture equivalent to about 50 billion tons of oil" [30]. The vegetation when grazed (used as food) by animals gets converted into zoo mass (animal biomass) and excreta. The excreta from terrestrial animals, especially dairy animals, can be used as

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a source of energy. Biomass resources have desirable prospects for large-range industries and local businesses. It is a renewable resource that has a steady and abundant supply, especially those biomass resources that are by-products of agricultural activity and organic matter. The outputs include a global assessment of biomass waste, development of a compendium of waste biomass conversion technologies and the assessment of environmentally sustainable technologies.

Renewable energy technologies are regarded as particularly suitable for population most widely affected by energy poverty. Furthermore, cost reductions over the last decade have made renewable energies more economically competitive compared with traditional fuels, which have also helped to strengthen the case for renewables. Nevertheless, these technologies still face a range of social, economic and structural challenges, requiring not only further technological development but also a deeper understanding of both the success factors and the barriers to accomplishing widespread dissemination. Small-scale projects can play a key role in supporting the transition toward more sustainable energy systems.

In Yemen, various sources of biomass, such as wood, crops, agricultural residues, industrial and municipal solid waste, tire waste, are considered as the main renewable energy resources available. Sewage of municipal, food industry and industrial waste is another potential source for the production of biomass fuel [10] which is available but still unutilized in Yemen.

The main purpose of this chapter is to highlight the status of solid waste management (SWM) and wastewater management (WWM) and to assess environmentally the potential conversion of biomass into energy in Yemen.

16.2 Biomass Resources

Yemen, Jordan and Egypt are major biomass generators in the MENA region, extensively using industrial and municipal solid waste in addition to agricultural residues by tradition as an energy source in rural households [37]. Natural gas recoverable reserves reported by 2014 accounted for 239 million tons with 268.9 billion m^3 proved reserves and with export of 93% of its total natural gas production mainly to South Korea (4.2 billion m^3). Three billion barrels of crude oil reserves were reported by January 2012, mainly located in Jannah and Iyad in central Yemen, Marib and Jawf in the north and Shabwa and Masila in the south. Estimated amounts of total oil exports and total oil domestic consumption were 103,000 and 157,000 billion barrels per day by 2010 [34]. The next sections provide more insight into municipal solid waste sources of biomass available in Yemen.

Table 16.1 MSW production in Yemen 2012

Population	24.5 million
Municipal solid waste generation	3.8 million tons
Per capita MSW generation	
– Urban areas	0.6 kg/day
– Rural areas	0.35 kg/day
MSW generation growth	3%
Medical waste generation	3916 tons/year
Industrial waste	No available data
Hazardous waste	20,917 tons/year
Agricultural waste	No available data
Waste tires	10,000 tons per year

SWEEP-NET [29]

16.2.1 Urban Wastes and Other Wastes

The Yemeni National Strategy for Solid Waste Management 2009–2013 categorizes solid waste (SW) similarly to the definition of the United Nations Environment Programme [31] into municipal waste (MW), construction and demolition waste, special waste (food processing and hazardous healthcare and industrial waste) and sludge. Urban MW is produced during daily activities of residents. In 2012, Yemen's population produced approximately 4 million tons (Table 16.1).

The largest part of MSW is composed of organic waste (65%), an estimation reported by the country report on the SWM in Yemen (Fig. 16.1). The following sections describe different waste sources as part of the biomass available in Yemen.

16.2.1.1 Municipal Solid Waste

Municipal solid waste (MSW) holds waste produced by households, the commercial sector including markets, the health sector utilities excluding hazardous waste, disposed furniture and foliage [23]. In 2008, 21 controlled or semi-controlled disposal locations and at least 27 open dumps were recorded in major cities of Yemen. Based on the estimated urban and rural MW generated a ratio of 0.6 and 0.35 kg/person/day, respectively, the total calculated annual waste generated was 3.2 million tons annually. These ratios are far below the estimated ratio of 0.8 kg/person/day in residential areas of less than 10,000 and 1 kg/person/day in areas of more than 10,000 residents [13].

MSW generated in Sana'a is approximately three times as that generated in Aden and four times that in Mukalla. Main causes are the high number of internally displaced people in these cities. All over, the waste generation has reduced since the outbreak of the war in 2015 for reduced levels of consumption per capita [12].

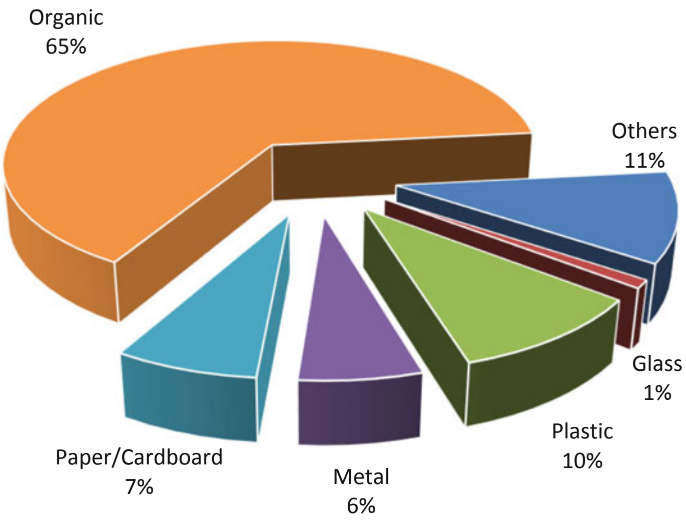

Fig. 16.1 Estimated composition of MSW generated in Yemen [29]

16.2.1.2 Food Industry Wastes

Food processing wastes comprise residues of the food processing industries, slaughterhouses, fish markets and carcasses [23]. Food industry waste is waste that does not meet particular quality control norms as peelings and leftovers of vegetables and fruits, and wastewater (rich in sugars, starch and other organic matters) produced by hotels, restaurants, confectionary and food industry [10].

The 2017,[1] World Bank report estimated an increase in Yemen's poverty from about 50% in 2015 to 62% driven by rising food prices and the reduction of purchasing power which has forced the poor to considerably lower their meal consumption while living on food leftovers discarded by richer households and restaurants and on market vegetable and fruit leftovers. Consequently, food waste has reduced which could be used as biomass resources for energy generation.

16.2.1.3 Animal Wastes

Practices to convert cattle manure into cowpats as a fuel source were widespread across Yemen before 1962 for household use, and public Hammams are still alive in rural areas of Yemen. Livestock manure is known for its high potential as a source of bio-fuel [10, 20]. Slaughterhouses constitute a source of infection with leptospirosis [6] and Brucella antibodies [4] among workers in different Yemeni cities. Animal waste from slaughterhouses is dumped with other MW on landfills.

[1] https://borgenproject.org/facts-yemen-poverty-rate/.

Table 16.2 Estimates of the total aboveground woody biomass growing stocks

Parameter used	Live wood growing stock
Total aboveground tree volume (mid-range point)	105.52 million m^3
Total aboveground tree volume (mean)	95.66
Total aboveground wet weight (mid-range point)	71.72 million tons (48.05)[a]
Total aboveground wet weight (mean)	53.84 million tons (36.07)[a]

[a]Air-dry weights (calculated using a conversion factor of the mean air-dry weight used)
Millington and Crosetti [23]

16.2.1.4 Fat, Oil and Grease

Main sources of fat, oil and grease (FOG) are mainly car oil change service stations and from industrial machinery, waste households, restaurants and hotels. No statistics on the amount of FOG are known. Waste lubricating oil is considered as special waste according to the Yemeni National Strategy for Solid Waste (2009–2013). A plan of action was set up to develop proper methods for the disposal and treatment of this waste up to 2011 with a foreseen governorate level-based approach for economic reasons. This was put on halt since the Arab Spring upraise.

16.2.1.5 Agricultural Waste and Woody Biomass

Millington and Crosetti [22] were the first who made a national estimate of woody biomass in non-urban, land-use zones in northern Yemen; see Fig. 16.2. Western Highlands, followed by the woodland and scrubland Tihama, proved to have most wood. In the Central Highlands, woody biomass is mainly found in poorly populated settings, wadis and high rainfall areas. For estimates of the total aboveground woody biomass growing stacks, see Table 16.2. Deadwood is widespread in non-agricultural land-use areas as in the bare and rangelands of the Central Western Highlands (3.149 tons per hectare of air-dry weight), while in the terrace agricultural Western Highlands only 0.003 tons per hectare was estimated [22].

Inaccessible or unavailable sources of cooking gas and eventually charcoal in rural and urban households leave people increasingly re-switch to fuelwood either collected for free or purchased from markets [21]. The increased destabilized economic crisis in Yemen during the past three years impelled poor citizens to harvest fuelwood for cooking in urban settings (Fig. 16.3), a task that is by tradition mainly reserved for women in rural areas. Wood as a source of char production is widely used in Yemen.

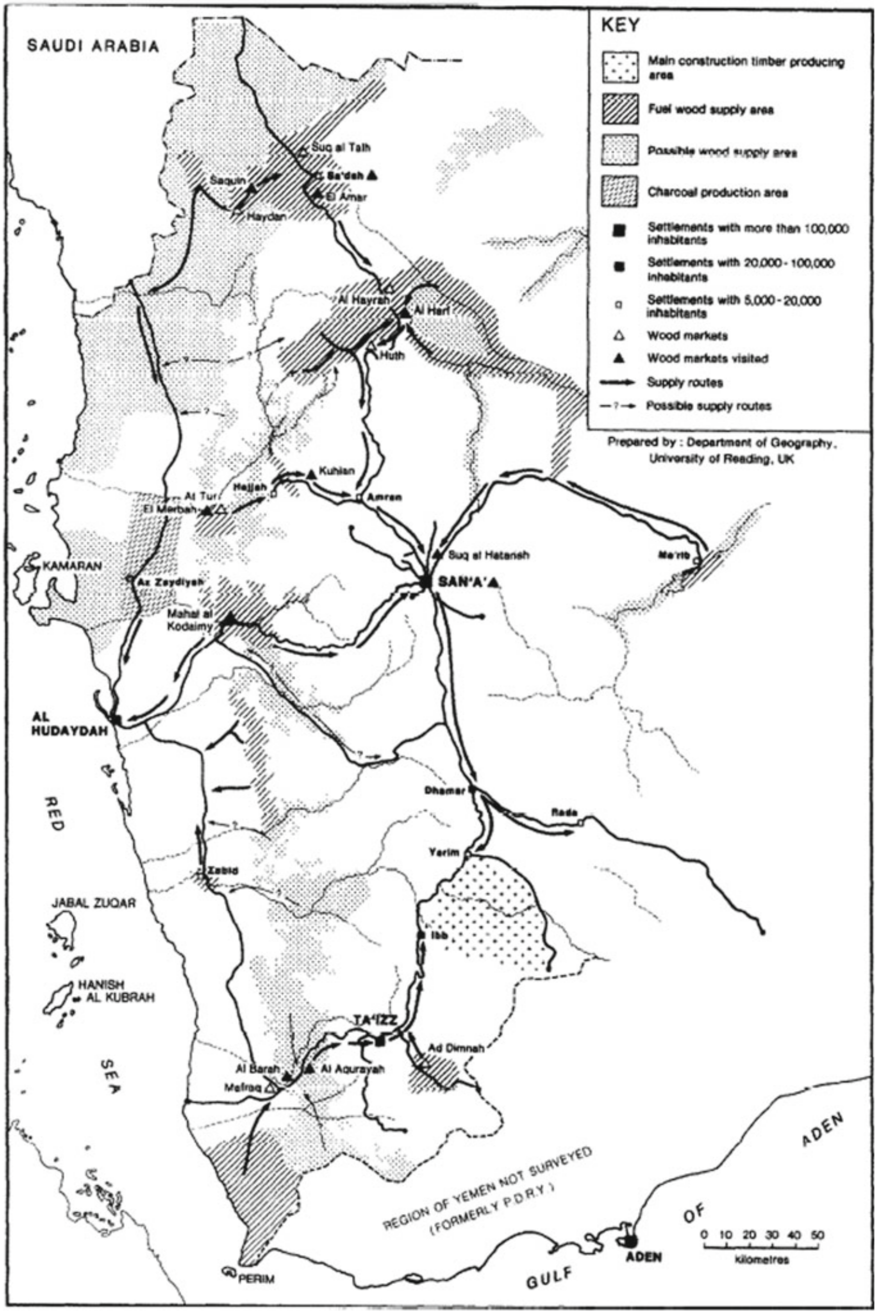

Fig. 16.2 Distribution of woody biomass resources in Yemen, with fuelwood supply routes [22]

Fig. 16.3 A man cuts a tree in a public sphere area; his wife collects the branches, Sana'a, Yemen Photograph by Bilkis Zabara

16.2.1.6 Green Waste

Green waste is considered as biodegradable waste generated by agricultural farms, gardens and parks. In Yemen, this type of waste is disposed with regular MSW in landfills since no policies are set up by the government, nor legal and institutional frameworks are regulating its management. No private sector is involved.

16.2.1.7 Industrial Waste

Hazardous industrial waste is considered flammable, corrosive, toxic, etc., waste produced by the diverse industries posing long-term environmental risks. Examples are metal, glass, tires, plastics and paints. In Yemen, this type of waste is disposed with regular MSW on landfills or discarded in sewage systems. Its total volume and composition are unknown.

No statistics on the amount of scrap tires disposed are available. Tires are used as alternative fuel in cement kilns but would cover only 14% of one of the seven kilns reported in 2014. About 1.36 tons of waste tires (estimated cost for 1 ton is $100) could replace one ton of heavy fuel of $640, thus saving annually about $3 million on a consumption rate of 10,000 tons [29]. The total number of new pneumatic tires of rubber for busses, cars and lorries reported in 2009 by the Central Statistical Organization (CSO) was 1.6 million. Assuming the total number of imported tires equals the number of waste tires, this amount could be used as an economic alternative for heavy fuel. Their collection, transportation and disposal require special equipment and legislation which are unavailable in Yemen.

16.2.1.8 Hazardous Medical Waste

Hazardous medical waste is highly infectious or chemically toxic waste (also considered as special waste) generated by healthcare establishments such as hospitals and health centers, clinics and laboratories [23]. In 2010, the estimated amount of this type of waste was about 4 million tons [29]. Guidelines to better manage hazardous medical waste were assumed to be drafted and distributed to healthcare facilities by 2010 under the responsibility of the Ministry of Health and Population (MoHP) and the Ministry of Local Affairs (MoLA). The total estimated investment requirements were set as ten million USD to achieve acceptable management between 2010 and 2013.

Hazardous medical waste produced in hospitals of rural and larger urban areas is estimated as 0.1 and 0.2 kg, respectively, per bed per day [29]. Clinical waste of 16,826 public beds as estimated by the WHO in 2012 was 0.5–3 kg/bed/day with an estimated mean of 9565.92–10,600.38 tons/year between 2008 and 2012 [11]. Infectious waste counts for an estimated 22%. This waste is disposed with regular MSW in hospital waste bins, presenting a health risk to healthcare workers and waste collectors and pickers.

For the first time, an incinerator was established in 2014 at Al-Azraqain landfill in Sana'a. This was hit by airstrikes a few months before it started operating. Incinerators are a tool to produce energy from untreated burned solid waste [32]. Hazardous waste has to be collected and treated separately to avoid environmental degradation [14].

16.3 Solid Waste Management in Yemen

SWM is limited to urban areas and absent on the rural level despite the rapidly increasing population in Yemen with an estimated 28.92 million and growth rate of 2.35% [35] generating thousands of tons of MSW daily. A key concern in sustainable MSWM could be participatory urban waste management [16]. In 2008, the collection and disposal of one ton of waste in Yemen were determined as US$16.5 for urban settings and half of this amount for rural areas, excluding public wages and maintenance allowances. Expenditures on disposal are rather very small for most likely open dumping practices [23]. Urgent interventions to rehabilitate this vital sector are a pressing issue [12]. A good example for WM is the 2008 UNDP initiated fish offal composting project in rural Bir Ali.

The management of solid waste is primarily the function of public institutions [28] which applies to Yemen under the umbrella of the Ministry of Local Affairs (MoLA).[2] Despite joint efforts of a sector-wide approach for coordinated action of the MoLA, the Ministry of Finance (MoF), the Ministry of Public Works and Highways (MPWH), the Ministry of Water and Environment represented by the Environmental Protection Agency (MWE-EPA), the Ministry of Planning and International Cooperation (MoPIC), the secretariat of the city and the involvement of local communities, MSWM is of low efficiency in all governorates.

The ongoing war since March 2015 led to the deterioration of the already suffering waste management services across the country. An emergency waste assessment survey conducted in 2015 revealed the partial damage and theft of vehicle fleet, heavy machinery and disposal sites, reduced fuel and electricity availability, the lack of financial resources to operate collection and transportation of waste and maintaining the system in Sana'a, Sa'dah, Hajjah, Aden, Taiz, Abyan and Hodeida [12].

16.3.1 Legislations

Clear definition of MSW, policies for waste segregation and the determination of quantities and composition of waste are crucial in legislations [14]. To improve solid waste management in Yemen, a National Strategy for Solid Waste Management 2009–2013 was developed and finally approved by Cabinet Resolution No. 181 for 2009, with a following stage to be started latest in 2014 [23]. Twenty strategic action points are addressed in this strategy aiming to set priorities, distribute roles and responsibilities in SWM, develop a sector-wide donor involvement mechanism, enhance financial resource allocation approaches, increase public awareness and a participatory community approach and make data collection and monitoring more efficient. Major challenges to enforcing these laws and regulations are the current instability of the country, in addition to the weak technical and financial resources to operate the waste management system holistically and efficiently in close collaboration with relevant stakeholders and actors.

The Republic of Yemen has ratified the Rotterdam Convention for sound chemical and waste management in its law no. 9 of 2005 [12]. In 1999, and under law no. 20, the Cities' Cleaning and Improvement Fund (CIF) was established to collect and manage revenue for SWM. In the same year, law no. 39 was issued (Public Cleaning Law) which was meant to define the roles, responsibilities and mechanisms of SWM of different types.

[2]In 2006, Presidential Decree 262 designated the responsibility of SWM to the Ministry of Local Affairs as the successor of the Ministry of Works and Housing.

16.3.2 MSWM—The Case of Sana'a City

Sana'a city, the capital of Yemen, also called Amanat Al-Asimah (the temporary capital since March 2015 is Aden) and one of the oldest cities worldwide, with an estimated population of 4 million in 2012 (the densest city of Yemen), is located in the northern part of Yemen at an elevation of 2300 m. MSWM poses the greatest challenges in urban settings globally, particularly in densely populated cities [38], including Sana'a. One major challenge is the current political crisis in Yemen. Local authorities operate waste management services on a crisis management system which breaks down from time to time particularly when municipal workers strike for their unpaid wages.

The generation of MSW and its disposal scheme have changed extensively in Yemen since the early 1960s till today. Direct disposal of MSW generated by households and shops into waste bins was the scheme in the 1980s and the 1990s. To avoid overfilled bins and their maintenance cost (technically and financially), bins were removed from streets and direct disposal from households onto waste vehicles took over. This mechanism could not sustain success. Residents (waste generators) kept dumping household waste (HHW) on roadsides increasing the risk of insect breeding and overrunning by rats. Waste is either loosely dumped on streets or enclosed in non-biodegradable thin plastic shopping bags of small to medium and large size (primary storage). Recyclables such as plastics, metal and glass are outsourced manually by waste pickers on the street level. The remaining waste excluding demolition waste (mainly kitchen waste) is loaded on small trucks either to a transfer station or directly to the landfill. The separated recyclable waste is sold to small waste-collecting centers, which further sell this waste to larger collection businesses. There, waste is shredded or baled and either recycled in the country, or the waste is exported. Figure 16.4 presents a flowchart of MSW collection, separation and transportation in Sana'a.

Statistical information on the generation, collection and disposal of waste in Sana'a is annually produced by the MoLA. Detailed information on the amount of waste disposed, the mechanism of transfer and dumping and at-source-segregation of recyclable waste and recycling mechanisms are described in the sections below.

The composition of generated MSW in Sana'a is categorized into dumps (food, plastic, metal, glass and textile) and dust including construction debris and demolition waste [8].

16.3.2.1 Waste Collection

The insufficient waste collection is a major concern of the municipality of Sana'a. Strategic Action No. 14 of the National Strategy 2009–2013 was set up to ensure expanded sustainable collection of MW with a possible intervention of the private sector. The monitoring of collection services including operational costs, weighing

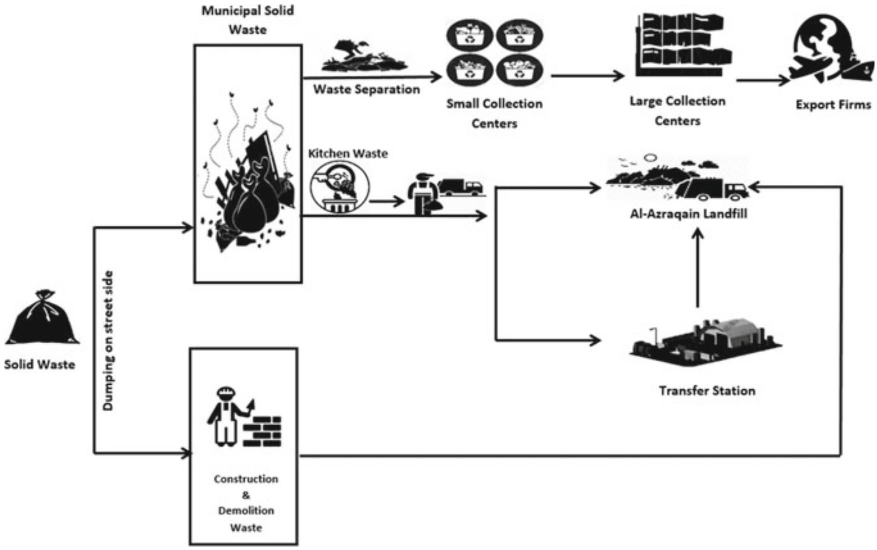

Fig. 16.4 SWM in Sana'a

waste produced and vehicle maintenance were of key issues of this strategy for optimal performance.

Al-Muhamasheen (a marginalized vulnerable group of Yemeni women and men with African origin) predominantly collect waste in Sana'a and are often treated badly by other community members. The increasing poverty in the country recently pushed other than this group to carry out city cleaning activities as well.

A trial of the local administration to turn from bin waste storage into a direct waste collection of generated HHW at the beginning of the twenty-first century failed to be successful. Vehicles that pick up waste from collection points after each meal (breakfast, lunch and dinner) could not keep up with transporting waste directly to the disposal site under the irregular disposal time pattern of residents. Nowadays, waste is collected from streets by a fleet of collection vehicles of high-sided open-top trucks and rear-loading compaction plate trucks two to three times daily.

Construction waste is generally dumped illegally in garbage places or in open spaces near to construction sites. More efficient regulations and mechanism to improve the deposition of construction and demolition waste and to avoid mixing up with MSW on landfills were supposed to be followed up in 2010 [23]. With the rise of the Arab Spring, this strategic action was put on halt.

16.3.2.2 Transportation

In a two-stage collection system, the segregated MSW of Sana'a is transported to the only transfer station (temporary primitive dumping site) of the capital located

Table 16.3 Basic information of SW disposal at Al-Azraqain landfill, Sana'a city 2017

MSW	Al-Azraqain landfill 2017	Transfer station 2017	Total 2017	Total 2016
Amount received in tons	421,521	54,957	476,478.64	483,236.90
No. of trips of waste vehicles	167,489	31,946	199,435	199,275
Average load in tons			2.39	2.42
Amount of diesel spent in liters			3,603,574	3,528,034

Amanat Al-Asimah [8]

in Asser area (Al Wahdah District) via primary collection vehicles. Hooklift trucks of 4 m^3 loading capacity and low maneuvering space in the small streets of Sana'a proved to be proper and more effective. The waste is then loaded on secondary bulk transport vehicles of larger capacities for efficient transport to Al-Azraqain landfill. In direct collection and for the sake of time, primary vehicles often directly transport the waste from the source to the landfill.

16.3.2.3 Disposal

MSW generated in Sana'a city is disposed at the approximately 3 km^2 fenced semi-controlled Al-Azraqain landfill located northwest of the city and established in 1980. This landfill serves in addition to Sana'a residents, citizens of Amran and Sana'a governorates. Table 16.3 indicates statistical information on MSW disposed at Al-Azraqain landfill [8]. Of the total volume dumped in 2017, about 47,000 kg accounts for dust while the great majority accounts for all other kinds of unseparated solid waste. Organic material is estimated to constitute over 60% of the total waste as reported by the Cities Cleaning and Improvement Fund.

Approximately 6758 tons less was dumped in 2017 than in 2016 despite the almost equal number of about 199,000 disposal trips and the increasing 35% IDPs (600–800 people) accessing UNHCR-supported center for daily aid assistance since the air, sea and land blockade on Yemen. It is to be said that both the transfer station and the landfill were hit several times by airstrikes causing immense damage to facilities.

The extermination of stray dogs reached 2636 in 2017, which accounts for 1025 dead bodies less than 2016. The carcasses of their dead bodies are dumped on the same landfill without separation.

Incineration with energy recovery is a common waste management strategy in Europe [9] with less greenhouse gas (GHG) emissions than landfilling and consequently a lower environmental impact. As mentioned previously, the brand-new incinerator installed at Al-Azraqain landfall was destroyed in an airstrike.

Fig. 16.5 A trailer full of plastic containers for export

16.3.2.4 Recycling

Major recyclable waste is separated prior to the collection by the municipality workers in addition to individual waste pickers (poor people including children, women, men and the Muhamasheen). They tip out the waste bags scattered on street sides looking for recyclable material, manually sort out the different types of waste and therefore play a key role in the recycling system. These recyclables mainly include polyethylene terephthalate (PET) and polyvinyl chloride (PVC) bottles, paper, cardboard and aluminum cans of soft drinks. Segregated waste is then sold per kilogram weight (one kilogram of bottles is sold for 30 YER) at smaller waste collection centers/shops/yards distributed over the city. These shops are male-operated family businesses which generally have their own high-sided open-top trucks to collect separated waste from shops, restaurant and street waste on a daily basis in two shifts between 7 a.m. and 7 p.m. When a truck is completely loaded with a certain type of waste (Fig. 16.5), it is transported to a larger company for shredding and compressing bale material. Baled metallic recyclables are weighed in a complete trailer on a weighing platform (often out of function) which are sold further to local export agents in addition to larger bulky metallic waste as vehicle scrap to countries such as the United Arab Emirates (UAE) while PVC and PET bottles are shredded and exported to China. The export to the UAE is currently on temporary cessation.

The economic benefit of recycling made this business lucrative and increasingly expanding among the private sector, while no laws are binding them. Public–private partnerships and community participation are known to be vital drivers of economic development and mitigation measures of environmental degradation [26]. Yemen could follow such a model particularly to regulate the recycling business.

In former times, specialized workers used to collect human excreta of the commonly known simple pit latrines, dry it in the sun and sell it as a fuel source to public bathhouses (Hammams). In the early seventies, the lifestyle of people living in cities has changed; flash toilets became more common for defecation in urban areas, and a sewage system was introduced in some urban areas to ensure a healthy living environment.

Ten Yemeni lubricating oil manufacturers are registered on the international Web site for the worldwide lubricating industry [19]. In 2003, Petroyemen for Oile (PECO) was established in Aden, the first Yemeni company for manufacturing of more than twenty different high-quality recycled oil and grease products to serve the local market across the country http://petroyemenlubricants.com/Defaulte.aspx. Formerly, waste lubricating oil was discarded on streets or in sewage systems. Nowadays, car service workshops which offer professional oil change collect this type of waste in underground tanks and sell it directly to final consumers such as bakeries and Hammams and for water pump operators. Heavy fuel oil and exhausted lubrication oil are also used as an energy source for cement kilns [12]. Waste oil is mixed with diesel and is used as an economically much cheaper alternative source for energy than pure oil. Waste lubricating oil is also sold to recycling purification (filtration) stations, and the relative clean product is then further sold to other consumers who mix it with pure oil or other fuel. The selling cost varies according to the international market[3] as per 208 L barrel between 15 and 25 thousand Yemeni rials (about 33–54 USD[4]). The car service business sells the lubricating oil waste in an unwritten agreement to the final consumer. The production of this type of waste has decreased in recent years due to the current economic crisis as an impact of the war and the unaffordable costs to maintain car engines. Waste cooking oil from restaurants is either discarded directly into the sewage system or disposed with MSW. The quantity disposed annually is unknown. Reasonable amounts could be an economic potential for biofuel with high engine efficiency and less emissions in reference to commercial diesel engines [18].

In 2010, four recycling establishments for batteries were operating in Yemen. Complying with environmental standards defined by the Yemeni Environmental Protection Authority (EPA) created a great financial challenge to factory owners and lead to evading rules.

One million thin plastic shopping bags (like pet bags) are estimated to be consumed in Sana'a on a daily basis, mainly for qat[5] sales. The uncontrolled production of this kind of undegradable waste often takes place in hidden cellars. Scattered all over the landscape after usage makes the collection of these bags extremely strenuous, while their light weight is economically unattractive for business recycling purposes. Yemen has pledged to prohibit the import of non-biodegradable. To make this vision become a reality, the political will must be demonstrated.

Wood waste is recovered on dumpsite level of Aden and Mukalla but not in Sana'a where recyclables are outsourced in earlier stages of waste separation and collection [12]. In Sana'a, wood is currently used as a fuel resource in addition to cooking gas.

[3]Interview with a car oil change service owner in Sana'a on July 8, 2018.

[4]http://ec.europa.eu/budget/contracts_grants/info_contracts/inforeuro/index_de.cfm.

[5]Also known as qat, a plant whose leaves are chewed mainly by adults and known for its stimulating effect https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2480814/pdf/bullwho00181-0028.pdf.

One small truck of wood costs approximately 30,000 YER (approximately $62.5 as of June 2018). To run a midsize bakery, this amount would be sufficient for about 4 days in addition to a 20 L cooking gas bottle.

In 2006, 90,000 tons of waste was recycled in four large Yemeni cities. A significant revenue of more than US$10 million was made from recycled plastic exports.

16.4 Biomass Conversion Technologies in Yemen

Biomass is a resource to produce renewable energy and fuels which are so-called bio-energy and biofuels. It is treated in several ways to recover different value-added products such as energy biogas (methane, hydrogen, syngas), liquid bio-fuels (bio-diesel, bio-oils), construction material (bricks, cement, pumice, slag, artificial lightweight aggregates), bio-plastic, proteins and hydrolytic enzymes, bio-fertilizers, bio-sorbent, biopesticides, electricity generation using microbial fuel cells, nutrients (nitrogen and phosphorus) and heavy metals. Anaerobic digestion, incineration, pyrolysis, gasification, wet air oxidation, supercritical water oxidation and hydrothermal treatment are the major techniques utilizing worldwide to treat the biomass waste for resource recovery (Table 16.4).

In Yemen, the use of biomass conversion technology is still limited. Solid waste materials could be potential feedstock for bio-fuel production. The production and use of liquid bio-fuels as alternative fuels are not examined.

Table 16.4 Waste biomass conversion to energy and bio-fuels

Technology	Conversion process type	Biomass waste	Energy or fuel produced
Bio-diesel production	Chemical	Rapeseed soybeans Waste vegetable oil	Bio-diesel
Direct combustion	Thermochemical	Agricultural waste Mixed waste	Heat, steam, electricity
Ethanol production	Biochemical (aerobic)	Sugar or starch Crops, wood waste Sludge rice and corn straw	Ethanol
Gasification	Thermochemical	Agricultural waste Mixed waste	Low or medium Btu producer gas
Methanol production	Thermochemical	Agricultural waste Mixed waste	Methanol
Pyrolysis	Thermochemical	Agricultural waste Municipal solid waste	Synthetic fuel oil (bio-crude) charcoal

UNEP [30, p. 15]

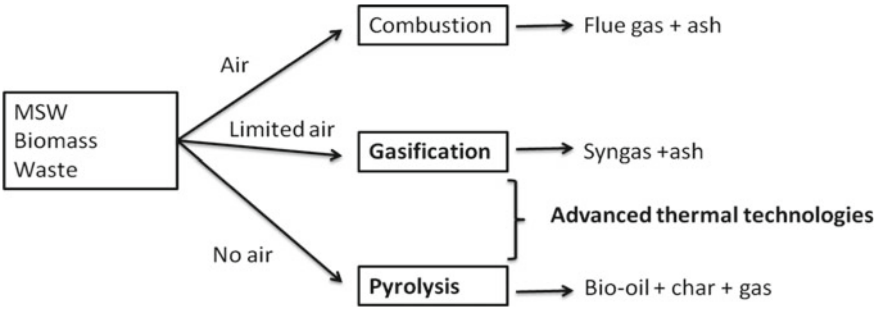

Fig. 16.6 Thermal conversion process of MSW biomass

The World Bank supported the development of municipal solid waste management for the production of biogas in Yemen since the 1990s through financing studies on solid waste management in 48 cities. Also, two biogas plants in the coastal zones of Shabwa were developed. In recent years, the World Bank funded the infrastructure investments for solid waste management through the Social Fund for Development (SFD). Other interventions included the feasibility study for municipal solid waste management systems in Sana'a and Taiz in 2010 and the promotion of household and village biogas plants for the treatment of fecal sludge manure and kitchen waste in 2012. In 2012, the World Bank started a project to enhance the production of biogas from manure in villages. This was disrupted in 2014 due to the residing conflict in Yemen [12].

In theory, approximately 6 MW of electrical energy could be generated from MSW dumped at landfills of the four major Yemeni cities, Sana'a, Taiz, Hodeida and Aden producing more than 100 thousand tons/year [27].

16.4.1 Thermal Conversion Processes

Pyrolysis is the thermal degradation of organic matter, sawdust, tire waste, sewage sludge in the absence of oxygen, and occurs at a temperature range of 400–800 °C. The primary pyrolysis products of biomass are usually referred to as condensable (tars) and non-condensable volatiles and char. The condensable volatiles (tars) are often classified as liquids (bio-oil), and non-condensable volatiles are gases mainly CO, CO_2, H_2 and C_1–C_2 hydrocarbons. Basically, pyrolysis can be categorized into conventional, slow, and fast or flash pyrolysis. Conventional pyrolysis, which occurs under a slow heating rate, has been employed for the production of charcoal [24].

In gasification, biomass is partially oxidized by controlling oxygen to produce combustible gases (Fig. 16.6).

In Yemen, it is estimated that approximately 3.8 million tons per year of municipal solid waste and 10,000 tons per year of scrap tires were generated in the country in

2012 [29]. “Agricultural methane emissions (% of total) in Yemen was reported at 46.78 % in 2010” [33].

In Yemen, only a single pyrolysis project has been reported. This project was implemented jointly by the Water and Environment Center, Sana’a University/Yemen and MetaMeta Research, the Kingdom of Netherlands [3]. It aimed for the preparation and characterization of activated carbon (AC) derived from sewage sludge for wastewater treatment using thermal pyrolysis scaled up in a laboratory process. The laboratory production of AC can be developed to industrial scaled applications.

16.4.2 Environmental Impact

Using biotechnology and thermal degradation of the biomass waste benefits the environment, while at the same time it may help solve some pressing environmental problems. The biomass waste-derived resource recovery will help to produce environmentally benign products, reduce the dependency on non-renewable resources. The biomass resources and bio-fuel production decrease greenhouse gas emissions associated. The use of biomass resources, managed in a sustainable way, could reduce CO_2 emissions and thus help tackle global warming. Methane is considered the major component in biogas production from materials as manure [17].

The use of municipal solid waste, agriculture waste and industrial waste which is abundant in Yemen, is an energy source for the production of bio-fuels. The use of the biomass could provide two important benefits, namely environmentally safe waste management and disposal, and clean electric power generation [15]. Production of bio-fuels from biomass could increase vegetation coverage and substantially improve the local environment.

16.4.3 Socioeconomic Implications

Economically, the utilization of biomass waste for the production of bio-oil, syngas, bio-plastic, bio-fertilizers, biopesticides, protein, hydrolytic enzymes is another area that shows the promising outcomes [24].

Yemen is one of the world’s most energy insecure and water-poor countries, with most of the country having lacked sustainable access to energy. Even before the conflict, rural areas only had 23% energy access rates while holding 75% of the national population. In general, energy supply in Yemen for many years has been very limited due to weak generation capacity of electricity, limited access, high losses from the grid and increasing demand.

In Yemen, biomass will be a varied effect: It would boost agricultural development, technological advancement, further bring opportunities and improve the quality of life. Also, the biomass resources can be converted to liquid and gaseous fuels, electricity and process heat, and they can increase access to modern forms of energy for the population. The dependency on energy imports and the risk of power supply cutoffs could be decreased by local generation of biomass [10]. The biomass resource cultivation, harvesting and processing could have a direct impact on rural development. The biomass and bio-fuel production could improve rural livelihoods by providing new income opportunities to their families. Bio-fuel production from the biomass should not be made to affect food security in the country. The production of bio-fuels by biomass resources should be made to avoid human health impacts and risks through regular training and awareness on the impacts of bio-fuel production process.

16.5 Yemen Water Issues

Yemen is considered a water-scarce country. The main resources of water in most cities are rain and groundwater. The high population growth rates, accelerated urbanization and rapid economic development have increased the pressure on water resources and have led to a continuous degradation of these resources endangering the long-term water sustainability. The situation in Sana'a city is extremely serious because of its high population density as a result of centralization and internal displacement. Currently, there are major challenges associated with the unsustainable management of water quality of the non-conventional sources in Yemen. The main source of water pollution comes from domestic, industrial and agricultural activities. Sewage contributes to the spread of diseases and environmental pollution [25]. Yemen suffers from inadequacy of water quality data and information, lack of awareness at all levels of management, lack of regulation and lack of coordination at the institutional level between several stakeholders. Additional challenges include the weak planning and funding of water and wastewater quality management.

16.5.1 Water Resources

Shortage of water resources is one of the most challenging problems of Yemen. Its surface water is estimated to be about 1500 million m^3/year. Several dams and dikes were built on many main wadis to direct spate waters into man-made spate irrigation systems, which irrigate around 120,000–150,000 ha [1]. According to the National Water Resources Authority report 2000, the total demand of groundwater was estimated as 3400 MCM while the renewable resource available was estimated as 2.5 MCM which posed a deficit of 900 MCM.

Rainwater is mainly harvested through dams and water constructions such as diversion weirs, concrete water tanks and canals. The purpose of these structures is to provide surface water for multi-usages. The final aim is to reduce groundwater extraction from deep aquifers, as well as to recharge the shallow aquifers from the reserved water in the dam reservoirs.

16.5.2 Wastewater Assessment

The total number of wastewater treatment plants in Yemen is nine stations in function. The total actual flow of the treated wastewater is around 92,000 m^3 per day and around 33.5 million m^3 per year [5].

Primary sewage sludge is generated in large quantities and poses challenges in safe disposal due to the presence of certain soil contaminants, such as organic compounds, pesticides, heavy metals and human pathogens. Most of the conventional means of sewage sludge disposal like open dumping, sanitary landfilling, aerobic and anaerobic digestion and incineration have created more serious problems like soil and plant toxicity, surface and groundwater contamination and air pollution. Furthermore, the ever-increasing cost and unavailability of land near urban areas, more stringent waste disposal regulations and public awareness have made open dumping and landfilling increasingly expensive and impractical [2].

The poor sanitation and the poor quality of sewage effluent from sewage treatment plants are the main causes of polluted water. According to an unpublished report by parliament's Water and Environment Committee 2006, waterborne diseases menaced 75% of the population, 55,000 children died off annually and three million people had hepatitis because of consuming unclean drinking water [5].

The disposal of sewage-treated effluents is an essential part of planning and designing sewage treatment facilities. After treatment, sewage-treated effluents are either reused or discharged into the environment. Yemen is the least advanced country among Arab countries in the sewage reuse and safety control as it has a predominantly rural setting, limited sewer connection, deteriorated wastewater treatment plants which do not meet the national quality requirement and reuse patterns which are completely uncontrolled [1]. Currently, sewage water is used in restricted irrigation. In Yemen, the farmers use it although still not yet treated enough for irrigation as seen in Table 2.5. For example, in Sana'a, Ibb, Taiz and Aden the sewage water after treatment is not legally for irrigation. However, some people open the manholes, clogging the effluent to stop the water flowing to the treatment system, and then pumping it to the fields for irrigation.

The farmers living near to the Sana'a wastewater treatment plant rely on sewage water by 95% to irrigate their cultivated areas. They abstract wastewater directly from stabilization ponds to irrigate a wide range of crops, especially qat which represents about 22.3% of the irrigated area. The management of treated wastewater plants and sewage sludge is considered one of the most significant challenges in wastewater treatment. Table 16.5 shows the characteristics of wastewater treatment plants in Yemen.

The treated water quality of wastewater treatment plants varies from a city to another. For example, the quality of wastewater in Hajja is considerably good while it is of very bad quality in Taiz, depending on the method of treatment as well as the capacity of the wastewater treatment plant and the operational circumstances. The current sewage effluent quality in Yemen is generally poor as none of the existing wastewater treatment plants produces effluents that comply with the effluent

Table 16.5 Characteristics of wastewater treatment plants in Yemen

Station	Design capacity (m^3/d)	Type of treatment	Actual flow (m^3/d)	Cost of treatment (U.S.$/$m^3$)	Disposal method	Disposal method of treated secondary effluent sludge
Sana'a	50,000	Activated sludge	37,000	0.25	Irrigation[a]	Fertilizer
Taiz	17,000	W.S.P. biological ponds	17,000	0.03	Irrigation[a]	Fertilizer
Hodeida	18,000	W.S.P. biological ponds	18,000	0.03	Sea + Irr	Fertilizer
Aden	70,000	W.S.P. biological ponds	17,000	0.03	Sea + Irr	Fertilizer
Ibb	7000	Activated sludge	7000	0.25	Irrigation[a]	Fertilizer
Dhamar	10,000	W.S.P. biological ponds	6000	0.03	Irrigation[a]	Fertilizer
Hajja	5000	Trickling filter	1150	NA	Irrigation[a]	Fertilizer
Mukalla	8000	W.S.P. biological ponds	6000	0.025	Sea	Fertilizer
Rada'a	2800	W.S.P. biological ponds	1500	0.025	Irrigation[a]	Fertilizer
Total	187,800		110,650			

[a]Uncontrolled irrigation
Al-Nozaily [7]

quality regulations. Yemeni laboratories are not equipped to measure all parameters. Researches on the efficiency of wastewater treatment plants in Yemen based on the microbiological analysis are very limited. The quality of treated wastewater is detailed in Table 16.6.

16.5.3 Wastewater Reuse

There are two types of wastewater reuse in agriculture.

Table 16.6 Treated water quality of wastewater treatment plants in Yemen

Parameter	Sana'a	Aden	Dhamar	Hodeida	Yemen standards
BOD (mg/l)	24	N.A.	102	106	150
COD (mg/l)	103	N.A.	189	348	500
TDS (mg/l)	1852	1695	700	3110	450–3000
SS (mg/l)	28	N.A.	580	128	50
FC/100 ml	12,000	80,000	110,000	1366	<1000

Al-Asbahi [5]

Table 16.7 Different treated water uses between 1990 and 2010 in Yemen in million m^3/year

Water use	1990	2000	2010
Agriculture	2600	3145	3328
Domestic	168	210	552
Industrial and mining	31	45	90
Total	2799	3400	3970

Al-Asbahi [5]

(1) "Controlled Irrigation: This is practiced by government projects of the Ministry of Agriculture and Irrigation (MAI) by building green belts mainly in the coastal plain cities (Aden and Hodeida), and for sand dunes' fixation or desertification control in the affected areas at coastal plains" (http://www.yemenwater.org/wp-content/uploads/2015/08/YemenWater.pdf).

(2) Non-controlled Irrigation: This is commonly practiced in the high lands and wadis by farmers who grow corn and fodder in some areas as in Taiz and who grow restricted and non-restricted crops like tomatoes, carrots and fruits as in Sana'a.

The agricultural sector is the largest user of treated water resources, while the domestic, industry and mining sectors are using 7–8%. The agriculture sector is using around 93% of the treated water resources (see Table 16.7).

16.5.4 Treatment Plant Issues

The main farmers' and institutional issues related to wastewater treatment are:

(a) Farmer issues

- Most stations produce poor-quality treated wastewater.
- Odor and insects are prevailing in some treatment wastewater such as in Taiz, Dhamar and Hodeida.

- Farmers have poor education and no experience to deal with low-quality water in irrigation.
- Treated wastewater represents a high public health risk impact; skin diseases are not uncommon.
- Animals suffer from some diseases due to direct contact with untreated wastewater.
- Soil damages due to uncontrolled uses of treated wastewater.

(b) Institutional issues

- Ineffective sewage management.
- Poor maintenance and frequent power cutoff in most treatment plants.
- Low tariffs and un-trained staff.
- Poor disposal of produced sludge.
- Wastewater produced by hospitals, hotels, factories, restaurants and car washing/lubricant change services centers is connected directly to the public supply networks without any pre-treatment.
- No monitoring and evaluation mechanisms are present, and no environmental impact assessment is conducted prior to the establishment of some treatment plants.

16.6 Conclusions

Few attempts to enhance proper SWM have increased in the last decades. The high demand on energy resources does not yet serve the rapidly growing population sufficiently. The utilization of biomass from solid and liquid waste at the same time mitigating environmental degradation weakly attracted the attention of the public and private sectors. Intensive research and socioeconomic and feasibility studies are required to find alternative solutions for WM. Joint efforts among relevant stakeholders and actors for efficient WM to reach international standards while considering the Yemeni context should be of priority.

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Chapter 17
Toward Three R's Agricultural Waste in MENA: Reduce, Reuse, and Recycle

Safenaz Shaaban and Mahmoud Nasr

Abstract The Middle East and North Africa (MENA) countries focus their efforts on developing the agricultural sector to face several challenges of unemployment, poverty, water scarcity, and political reactions. Agricultural practices include animal husbandry, food processing activities, and irrigation, harvesting, transfer, and storage of field crops. These actions result in the generation of million tonnes of organic and inorganic wastes per year including crop residues, livestock manure, and chemical and biological fertilizers. Agricultural wastes should be appropriately managed to avoid serious environmental concerns such as eutrophication of surface water, groundwater contamination, odor emissions, and deterioration of soil, water, and air. Hence, this chapter demonstrates the strategies of agricultural waste management in the MENA region regarding the available land, water, and energy resources. The threefold solutions of agricultural wastes are (a) reduction via improving irrigation efficiency, developing cultivation strategies, minimizing chemical fertilizers, applying control and process monitoring schemes, investing in agricultural sectors, and increasing environmental awareness and education, (b) reuse in irrigation, fertilization, bio-energy production, pyrolysis, direct combustion, animal feed, and pollutant adsorption, and (c) recycling through civil construction and composting approaches. These strategies are presented regarding case studies reported in the literature for stimulating agricultural waste management in the MENA region.

Keywords Agro-waste management · Agro-waste quantity and quality · Biomass and bioresource · MENA agricultural activities · Three R's agro-waste

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17.1 Introduction

The Middle East and North Africa (MENA) region, which retains almost 6.3% of the world's population, covers several countries of North African, Gulf Cooperation Council (GCC), and Eastern Mediterranean [4]. The MENA zone contains only 1.4% of the world's renewable freshwater, and it allocates over 85% of the available water resources to the agriculture sector [40]. For example, the percentages of water utilization for agriculture in some MENA countries are 69% Algeria, 88% Egypt, 92% Iran, 75% Jordan, 72% Lebanon, 93% Morocco, 90% Saudi Arabia, 96% Syria, 87% Tunisia, and 96% Yemen [39]. Due to the limited application of agricultural waste reuse, most MENA countries face water shortage and scarcity. Moreover, the expanded agricultural activities in the MENA region has resulted in increasing the quantities of livestock wastes, agricultural crop residues, and agro-industrial by-products [18].

Agricultural wastes can be managed in terms of [31, 47] (a) generation, (b) collection from the point of deposition, (c) storage or rapid utilization, (d) reduction in pollution using physical, biological, and chemical treatments, (e) transfer from the collection point to the reuse stage, and (f) recycling for beneficial applications. These actions attempt to limit the negative impact and toxic potential of agro-wastes on the environment while saving resources [25]. In this context, recent studies have attempted to improve the technologies used for the reduction, reuse, and recycling of agricultural wastes [7, 28].

Hence, this chapter represents the application of "three R's" approach of agricultural wastes in the MENA region. The threefold objectives are (a) reduce (minimize) the quantities of generated agricultural wastes, (b) reuse the waste products (or parts of items) after appropriate treatments, and (c) recycle the waste to generate useful items and add value to the deteriorated resources. Previous studies that have applied the "three R's" concept of agricultural wastes are also presented.

17.2 Middle East and North Africa (MENA) Description

The MENA region covers an extensive area of approximately 15×10^6 km^2, stretching from Morocco to Iran. Siddiqi and Anadon [40] classified the MENA area into five subregions, as follows (a) Egypt, (b) North African countries of Libya, Tunisia, Algeria, and Morocco, (c) Yemen and six Arab states of GCC (i.e., Saudi Arabia, Bahrain, Oman, Emirates, Kuwait, United Arab, and Qatar), (d) Eastern Mediterranean countries, viz. Syria, Israel, Lebanon, Jordan, and Palestine, and (e) Easternmost geographical zone of Turkey, Iran, and Iraq. This large area accounts for 6% of the world's population with a growing annual rate of 1.8% [18]. The MENA region holds some countries of the world's largest oil and natural gas producers and exporters, and it has access to only 1.4% of the world's renewable freshwater.

17.3 Agricultural Waste Components

Agricultural wastes, also known as agro-wastes, are recognized as any residues obtained from the growing and processing of agricultural products [31]. They can be collected in the liquid, slurry, and solid forms. The classification of agricultural wastes depends on the method and type of agricultural activities [14]. For instance, dairy product processing produces biological sludge, whereas animal/livestock generates manure. Stover and straw are generated from crop production, while branches, bark, leaves, and sawdust are obtained from timber and wood processing [1]. Based on the type of agricultural activities, liquid wastes occurring from the urine and cleaning/washing of animals, as well as, sanitation systems in slaughterhouses can account for the major volume of agro-wastes [28].

Agricultural wastes compress [8, 33] (a) wastewater containing nutrients, herbicides, pesticides, and insecticides, (b) field wastes (e.g., weeds, roots, bagasse, leaves, and straws), (c) animal/livestock wastes (e.g., carcasses, manure, excreta, and poultry litter), and (d) agro-industrial wastes (e.g., sugarcane bagasse, potato peels, corn stalks, and other food processing residues).

Agricultural wastes can also be classified into biodegradable and non-biodegradable residues [20]. Biodegradable wastes are composed of a high fraction of organic compounds, which can be subjected to digestion, decomposition, and degradation processes via the action of microorganisms [35]. Non-biodegradable wastes cannot be treated by microbial actions as they contain metal, plastic, pesticide, and oil products.

Agricultural wastes can also be categorized into primary residues such as leaves, stems, and seed pods that are obtained in the field after harvesting, and secondary wastes that remain at the processing facility (e.g., bagasse, roots, husks, and molasses) [21]. Straw waste is obtained from croplands of broad bean, lentil, barley, wheat, flax, and rice, whereas pruning residue is released from farmlands of grapes, citrus, palm dates, and olives. Cultivation of sesame, maize, sorghum, sunflower, and cotton generates stalk waste. Moreover, farming of soybeans, sugar beet and peanuts generates haulms, and sugarcane farms produce bagasse [45]. Animal manure and urine are produced from livestock activities of chicken and cattle.

17.4 Agricultural Waste Quantity

Agricultural wastes occur during cultivation process (e.g., farmland construction, seeding, irrigation, and fertilization), harvesting and gathering of agricultural products, and post-harvesting such as compaction, separation, storing, transporting, and marketing. The amount of crop waste production can be estimated by Eq. 17.1 [14].

$$\mathrm{CR}_{\mathrm{tot}} = 0.42 \times A \times \mathrm{CR}_{\mathrm{rate}} \tag{17.1}$$

where CR_{tot} is total crop waste per year (tonnes/year), A is cultivated area (Feddan), CR_{rate} is generation rate of farm residue per unit of area per year (tonnes/ha/year), and "0.42" is area conversion factor (1 Feddan = 0.42 ha).

The production of livestock wastes (i.e., cattle and chicken manure) is calculated by Eq. 17.2 [14].

$$LR_{tot} = M_{hadd} \times LR_{rate} \tag{17.2}$$

where LR_{tot} is total quantity of manure generated by particular animal category per year (tonnes/year), M_{head} is the quantity of manure generated for the head of each animal category per year (tonnes/head), and LR_{rate} is the number of animals for an animal category per year (head/year).

Most MENA countries rely on the agricultural sector as the main source of national income, consuming about 87% of the total water withdrawal. The widespread crops in MENA are wheat and barley [39]. Moreover, some MENA countries such as Egypt, Tunisia, Morocco, and Saudi Arabia produce considerable amounts of maize and rice. This approach results in the generation of million tonnes of agricultural wastes per year, which have reached a critical level. For example, Egypt is recognized to be from the top producer of rice and cotton in the world. Egypt contributes to the production of approximately 30 million tonnes of total residues per year, classified as wheat straw 37.7%, maize stalk 16.6%, fruit tree pruning 12.3%, sugarcane bagasse 11.0%, rice straw 10.7%, sugar beet haulm 4.2%, and others [14]. The cattle manure production is 13 million tonnes per year for the Upper Egypt region and 10 million tonnes per year for the Middle Egypt area [14]. Moreover, Saudi Arabia generates over 200,000 tonnes of date palm biomass per year, containing agricultural wastes of seeds, stems, leaves, and pits.

17.5 Negative Impact of Agricultural Wastes

Agricultural wastes can pose negative consequences to the environment and severe hazards to human health as they contain organic and inorganic matters, toxic chemicals, and microbial species [34]. For example, runoff from agricultural land comprises high nitrogen and phosphorus contents that can accelerate eutrophication of surface water such as lakes and ponds [1]. Eutrophication is limited by the control of the total P concentration in streams as not to exceed the critical value of 0.02 mg/L. Moreover, the unbalanced nitrogen and phosphorus ratios in agro-wastes can increase the growth of unsuitable algae and aquatic weeds in water bodies, leading to oxygen depletion [3]. A portion of fertilizer is retained in the soil and further contributes to groundwater contamination. Furthermore, wastewater containing pesticides may cause harms to the farmers, agricultural land, and food [38]. The H_2S, CH_4, and odor emissions emanating from the putrefaction/decomposition of organic matter in livestock and redundant crops can generate greenhouse gases and cause air pollution.

Additionally, pathogens and antimicrobial compounds in animal manure can cause significant deterioration of soil, water, and air quality [37]. In this context, agricultural wastes should be adequately managed to reduce their negative impacts on the environment, viz. soil degradation, desertification, and water pollution.

17.6 Agricultural Wastes Three R's Concept

Agricultural wastes are considered as undesirable and unwanted substances derived from various agricultural practices. The approach of three R's of agricultural wastes includes reduction, reuse, and recycling steps, providing several benefits to the air, soil, and water environments.

17.6.1 Reduction of Agricultural Wastes

The agricultural sector plays an essential role in the economics of the MENA region. Accordingly, the excessive quantities of liquid and solid wastes generated from various farming practices represent a high pollution load. The reduction approach aims at either minimizing the creation of wastes or achieving zero waste during agricultural practices. This step can be realized by the following processes:

1. ***Decrease water withdrawal***

A high portion of freshwater withdrawals is used for agricultural practices, and hence, it is crucial to provide additional water supplies that can cope with water scarcity and shortage. The strategies used to decrease the dependence on freshwater resources for irrigation include rainwater harvesting, sewage water recycling, and desalination and brackish water exploitation. Water withdrawal describes the total amount of water discharged from surface water or groundwater source [2]. The total water use for agricultural purposes is the summation of consumptive water use and water resources lost during irrigation. Consumptive water use refers to the water released from watershed by evapotranspiration (i.e., transfer of water to the atmosphere by surface evaporation and plant transpiration) during the crop growth stage. This portion of water is permanently lost and will not return to the water resource system [44]. Water productivity estimates the correlation between crop production and total water use, and it can be represented as the actual yield per unit of water utilized. Cao et al. [8] found that water productivity could be improved without an increase in water withdrawal. Their comprehensive perspective [8] attempted to reduce the amount of total water use in agricultural activities via a comparison between irrigated and rain-fed farmlands while achieving a sufficient food supply.

Du et al. [12] reported that deficit irrigation is a promising approach that can cope with water scarcity, maintain water productivity, and induce the plant physiological responses. Their work [12] presented the following strategies to maintain sustainable and efficient agricultural water resources (a) enhance crop yield without an increase in the rate of evapotranspiration (or minimize evapotranspiration without yield reduction), (b) establish compensatory mechanisms to promote agricultural water saving for cropland owners and farmers, (c) encourage agricultural land circulation, (d) adopt robust, economic, and efficient equipment in the agricultural sectors, (e) develop researches on water-saving agricultural techniques, (f) implement efficient sprinklers, smart irrigation controllers, evapotranspiration monitoring, and soil moisture sensors, and (g) recycle water and construct landscapes for water conservation.

2. ***Improve irrigation strategies***

The approaches used to improve the irrigation methods include subsurface irrigation, drip irrigation with plastic mulch, sprinkler irrigation, surge flow irrigation, and micro-irrigation [19]. A center pivot irrigation system, which uses portable tubing equipment that pivots around a center point connected to a source of water, is a practical option for reducing water loss during irrigation [29]. Sezen et al. [38] compared between drip and sprinkler irrigation schemes for efficient water productivity of sunflower production in silty-clay-loam soils. Their work [38] demonstrated that both partial root zones drying in the drip system and deficit irrigation in sprinkler scheme provided adequate irrigation strategies under water scarcity conditions. Lu et al. [24] investigated the effect of drip irrigation on the production of crops using reclaimed water and groundwater. Their work [24] indicated that irrigation by reclaimed water provided essential nutrients for plant growth, leading to improving yield and quality of fruits and vegetables. Cavero et al. [9] depicted that the yield of alfalfa was improved with an increase in the irrigation applied using sprinkler from 55 to 115% of the theoretical crop irrigation requirement. Kresović et al. [19] investigated the effects of deficit irrigation using the sprinkler irrigation system on maize crop yield. Their work [19] found that the grain yield was improved by 47.8, 32.8, and 22.9% for 100, 75, and 50% of full irrigation amounts, respectively, compared to the rain-fed treatment. However, water productivity was highly variable and low under rain-fed irrigation, which could be due to the rainfall distribution during the plant-growing seasons.

3. ***Minimize chemical fertilizers***

Excessive application of chemical fertilizers is economically unfeasible, and it can cause potential risks to soil quality. Agricultural wastes contain sufficient amounts of organic matter and nutrient elements, and thus, they can be used to improve the soil physical, biological, and biochemical properties. Li et al. [22] presented a strategy to reduce the dependence on chemical nitrogen, phosphorus, and potassium (NPK) fertilizers for maize crop production. Their work [22] recommended the combined strategy of chemical and organic fertilizers, in which NPK fertilizers could be partially exchanged by manure when the soil organic carbon reached 41.96 Mg C/ha. Akhtar et al. [2] found that the addition of biochar to the sandy-loam soil could improve the water use efficiency and tomato crop productivity and quality, compared to the non-biochar irrigation. Their work [2] demonstrated that the application of biochar treatment combined with partial root-zone drying irrigation could be a promising scheme under limited freshwater conditions. Ning et al. [30] found that the chemical–organic fertilizer fractions of 60:20 and 40:40 could modify soil organic matter and enhance catalase and urease activities, compared to the chemical fertilizer fraction of 100%. Liu et al. [23] depicted that the application of P_2O_5 of 360 kg/ha (as P fertilizer) or manure of 150 t/ha considerably improved Chinese cabbage yield, as compared to the unfertilized treatment.

4. ***Quality control and process monitoring***

Recently, computer simulation models have been employed to evaluate and predict various agricultural irrigation management practices. Several crop modeling software packages attempt to minimize water losses from excess irrigation. For example, Tian et al. [44] presented surface water–groundwater interaction model to study the impact of agricultural water on the hydrologic cycle and to avoid the depletion of the groundwater storage. Chen et al. [10] proposed a soil and water assessment model for the prediction of evapotranspiration and irrigation magnitude and frequency. The developed auto-irrigation algorithm could be used to avoid water stress conditions [10]. A review article by Ruiz-Garcia et al. [36] presented the common wireless sensor technologies used for monitoring different environmental factors that affect water utilization in croplands. Nikolidakis et al. [29] employed wireless sensor networks to manage water supply in cultivated fields for tomato production automatically. Their work [29] depicted that network lifetime using the automated scheme was improved up to 1825 min.

5. ***Investment in agricultural sector***

Increased water demand to maintain sufficient crop production has encouraged decision makers to apply strategic plans for investments in agricultural water management. The plans for comprehensive irrigation investments include [28] (a) increasing the area under irrigation, (b) improving the use of fertilizers and hybrid seeds, (c) promoting rainwater storage structures to sustain crop production during drought and dry seasons, (d) offering training and market developments, and (e) rehabilitating and constructing irrigation infrastructure. Irrigation infrastructure includes aqueducts, dams/reservoirs, flow-regulating structures, pumping stations, canals, drains, and sprinkler and drip systems. Ward [47] summarized the factors influencing the investments in irrigation infrastructure and delivery systems that can reduce the agricultural water losses. The factors were classified into the market and institutional approaches. The market mechanisms include nonvolumetric pricing, infrastructure subsidies, marginal cost pricing, and water markets, transfers, and rights. The institutional approaches include water user associations, irrigation institutions, regulatory solutions, and transboundary agreements.

6. ***Environmental awareness and education***

Several habits and attitudes in MENA have been noticed to increase the environmental pollution caused by agricultural practices. For instance, farmers discard most of the packages and containers holding pesticides into rivers and fields. Moreover, the incorrect manner of packaging and storage results in the generation of various types of wastes and pollution. Hence, the effectiveness of reducing agricultural wastes is closely associated with the perception and awareness of the population toward the environmental crisis. Environmental protection is the responsibility of children, employees, and all citizens [25]. Continuous training in schools and universities should be implemented to improve the students' education regarding waste generation and the reduction, reuse, and recycling routes. In an environmental education system such as "Zero-waste campus," students realize that agricultural wastes can be recycled into valuable resources. Several school and university education systems have recently established the idea of a "greening" university campus. Students are encouraged to understand the concept and design of sustainable waste reduction [11]. Awareness and education programs should also consider recycling as an alternative method to disposing of wastes. These programs are authorized to farmer training organizations, agricultural researchers, and governmental and non-governmental media. Hence, environmental awareness should be an integral and principal objective of education for all individuals of society.

7. ***Other waste reduction solutions***

The reduction in agricultural wastes in MENA can also be achieved via several processes including (a) decrease water utilization during irrigation, (b) reduce wastes' volume via segregation, sorting, and compaction, (c) improve installation and maintenance of irrigation equipment, (d) exchange waste as a raw material for other processes, (e) enhance harvesting, handling, and storage techniques, and (f) improve irrigation infrastructure.

17.6.2 Reuse of Agricultural Wastes

Although treated agricultural wastes have been recognized as a valuable non-conventional resource, the application of agricultural wastes reuse in most MENA countries is insufficient. Several approaches have been employed for efficient reuse of agricultural wastes. For example, the treated agricultural wastewater can be used for limited irrigation, excluding crops that are eaten raw. Moreover, agricultural wastes can be reused to obtain valuable products such as biogas, biofuel, bio-oil, biochar, chemical fertilizers, and animal feed, leading to avoid the transmission of hazardous materials. These approaches can be described as follows:

1. ***Irrigation***

The reuse of treated agricultural wastewater for crop irrigation has been recognized as a viable solution in many countries of the MENA area that suffer from water deficiency and frequent drought periods [40]. Moreover, agricultural wastewater reuse protects potable resources and minimizes the environmental impact resulted due to the discharge of polluted effluents into water bodies. However, the irrigation of croplands by treated wastewater should be conducted under strict regulations to avoid imbalanced nutrient supply, the health risk to consumers, and hazards to groundwater, soil, and plants [48].

Moreover, the level of awareness and education about the reuse of agricultural wastewater for irrigation should be enhanced among farmers and crop consumers. Recently, the revised and restricted guidelines for safe reuse of wastewater in the agricultural domain have been reported by the World Health Organization [48]. Libutti et al. [21] investigated the utilization of reclaimed agro-industrial wastewater for irrigating tomato and broccoli crops under Mediterranean conditions. The secondary treated wastewater was attained by screening, oil and grease removal, equalization, and activated sludge process, whereas the tertiary treated wastewater was obtained by the secondary treatment in addition to sand filtration, ultrafiltration, and UV disinfection. Their study [21] demonstrated that the yields and essential qualitative parameters of crops were not negatively affected by the irrigation with tertiary treated wastewater, compared to raw and secondary treated wastewaters.

2. ***Fertilization***

The utilization of animal manure has been reported to enhance soil fertility and improve soil structure stability and physical condition. Sileshi et al. [41] found that the integration of animal manure to chemical fertilizers to enhance nutrient contents in soils should consider (a) manure collection, storage, and composting, (b) spot-application (e.g., hill placement) of manure, (c) manure stoichiometry and essential N, P, and K for growth, (d) soil physical and chemical properties, (e) site-specific irrigation framework, and (f) climate variability. Qian et al. [33] reported that the co-existence of trace element and antibiotic in manure-based fertilizers should be considered to avoid environmental and ecological risks.

3. ***Bio-energy***

Egypt of the MENA region can produce sustainable bio-energy from various agricultural wastes such as cotton stalk, rice straw, pruning, maize stalks, sugar cane bagasse, and cattle manure [14]. Agricultural wastes provide a high-solids organic feedstock that can be used for the biological conversion of biomass into energy [37]. Obi et al. [31] reported that organic wastes could reach up to 80% of the solid wastes produced from agricultural farms.

The amount of residues mobilized for bio-energy production can be calculated by Eq. 17.3 [14].

$$CR_{bioen} = CR_{tot} - CR_{soil} - CR_{utilized} \tag{17.3}$$

where CR_{bioen} is crop wastes employed for bio-energy production (tonnes/year), CR_{soil} is the quantity of plant wastes used for the soil (tonnes/year), and $CR_{utilized}$ is the amount of crop residues utilized for other applications (tonnes/year).

The amount of livestock waste that can be used for bio-energy generation is calculated by Eq. 17.4 [14].

$$LR_{bioen} = LR_{tot} - LR_{utilized} \tag{17.4}$$

where LR_{bioen} is the quantity of manure produced by a particular animal category per year (tonnes/year), and $LR_{utilized}$ is the quantity of manure from a particular animal category utilized for other applications (tonnes/year).

The reuse of agricultural wastes, especially animal manure, can be a viable and environmental-friendly resource to obtain CH_4-rich biogas via anaerobic digestion. In this biological process, the complex organic compounds are hydrolyzed and converted into simply and readily biodegradable substrates. Further, acidogenic and acetogenic bacteria convert the sugars into volatile fatty acids and soluble products, which are utilized by methanogens to obtain CH_4 gas [1]. Generally, the biogas produced by anaerobic digestion contains about 50–70% CH_4, with a heating value in the range of 18–25 MJ/m^3. Also, the digestate, containing partially digested feedstock, can be diluted with irrigation water and used in agricultural land to maintain soil fertility. Abouelenien et al. [1] found that the co-digestion of chicken manure with agricultural wastes enhanced the CH_4 yield by 93%, corresponding to 403 L/kg, as compared to only chicken manure substrate. Reddy et al. [35] indicated that sugarcane bagasse was subjected to steam-acid treatment, and the hydrolysate was used to obtain 0.874 mol- H_2/mol-glucose via dark fermentation.

4. ***Pyrolysis***

In the pyrolysis process, agricultural wastes are subjected to thermal degradation at a temperature of 400–600 °C in the lack of oxygen (inert atmosphere) to vaporize the chemical constituent of the biomass and obtain biochar, bio-oil, and gas products [34]. Other techniques such as gasification and combustion of agricultural biomass can also be used for biochar production. Wang et al. [46] investigated the pyrolysis mechanism using agricultural wastes of rice straw and corn stalk. Due to the formation of tar-derived volatiles, the mean activation energies obtained from the pyrolysis of the two agricultural hemicelluloses was approximately 150 kJ/mol [46]. Lee et al. [20] investigated the pyrolysis process of agricultural wastes (i.e., red pepper stalk). Their study [20] depicted that the use of CO_2 as a pyrolysis agent could maintain biochar fabrication, energy saving, enhanced syngas, and waste management. The effects of several factors such as temperature, reaction time, pressure, biomass particle size, carrier gas flow rate, heating rate, catalyst, and pyrolyzer bed height on the pyrolysis process have been reviewed in a study by Tripathi et al. [45].

5. ***Direct combustion***

Agricultural wastes can be completely combusted to obtain energy and other oxidation products. The combustion process undergoes three stages, viz. water elimination, roasting, and char oxidation. This thermal conversion process is used for mechanical and steam applications, charcoal fabrication, heating, and cooking. Garcia-Maraver et al. [17] found that the combustion of agricultural wastes of olive wood, leaves, and pruning at a temperature <180 °C obtained activation energies of 42.48, 39.40, and 37.06 kJ/mol, respectively. Quispe et al. [34] summarized the recent literature studies that have employed direct combustion of rice husk to generate energy. However, the main drawback of the direct combustion of wastes is the release of toxic substances such as particulate matter, acid gases, and nitrogen and sulfur oxides.

6. ***Animal feed***

Although agricultural wastes have high fiber content, they contain low fractions of essential elements such as protein, starch, and fat. The low protein content limits the application of agricultural wastes as an alternative supplement for animal feed. Surendra et al. [42] investigated the farming of *Hermetia illucens* on organic waste to obtain protein-rich biomass, which was used for animal feed applications. Nannyonga et al. [26] found that banana waste was subjected to solid-state fermentation and anaerobic digestion processes, leading to improving the protein content by 7.9 and 6.7%, respectively. Further, the modified banana waste could be used as animal feed supplements [26]. Azizi et al. [4] reported that agricultural wastes originating in the Middle East region such as pomegranate, citrus, and grape wastes and apple by-products could be adopted as feed ingredients in poultry diets. These wastes provided positive impacts on growth traits, carcass quality, health status, and meat yield of poultry [4]. However, the shortness in the agricultural waste reuse for animal feed is attributed to high production rates along with low-to-medium rates of treatment.

7. ***Adsorption of pollutants***

Recently, rapid industrialization and unplanned urbanization have resulted in the release of excess amounts of heavy metals into the environment [15]. Heavy metals accumulate in soil and plant, causing health risk via consumption of contaminated fruits, vegetables, and other food crops. Adsorption has been considered as a promising technique for the uptake of heavy metals and other toxic elements from wastewater [27]. Agricultural wastes can be used as a renewable, cost-effective, and efficient source of adsorbents for the removal of various types of aquatic pollutants. Moreover, agricultural wastes can be chemically treated to improve the adsorption capacity by increasing the number of functional groups and binding sites. Fawzy et al. [15] found a removal efficiency of 63.4% within 180 min for the adsorption of Ni(II)-ions from aqueous solution by *Potamogeton pectinatus*. The adsorption schemes included the formation of organometallic complexes with the functional groups of –COO–, –OH, –C=O, and –OH, as well as, ion exchange and electrostatic attraction mechanisms [15]. Fawzy et al. [16] depicted that *Oryza sativa* was able to eliminate Cd(II)-ions from synthesized and real wastewater samples with removal efficiencies of 89.4 and 100.0%, respectively.

17.6.3 Recycle of Agricultural Wastes

Any ecosystem is self-organized to recycle all types of wastes with maximum efficiency; however, human activities can also contribute to the recycling process. Recycling of agricultural wastes is the breakdown (or treatment) of biomass residues to reclaim valuable materials, which are then processed to obtain new products [6]. This trend is economically beneficial in the MENA countries, owing to the enhancement of the quality of air, water, soil, plant, and animal. A typical recycling process passes through multiple steps including gathering, washing/cleaning, drying, sorting/segregation, and processing. However, the presence of solid particles, glasses, stones, and metals in agricultural wastes can cause damage and abrasion to the shredding machines. Moreover, the oil and grease contents might impede the recycling process as they require the addition of detergents during washing. Agricultural wastes should be recycled rapidly because stagnant wastes make flies and insects breed, foul odors emissions, and diseases spread. Also, the storage process should be maintained under suitable conditions to avoid spoilage of the desired end product [21]. The market for recycled items is not well recognized by customer satisfaction due to market and technical unacceptance. Consumers are not keen to accept recycled items due to the lack of a clear vision about recyclates, and health and safety essentials. For example, recycled plastic materials are not considered safe for food packaging as they can detriment the final food-contact product. Examples of agricultural waste recycling can be represented as follows:

1. ***Civil construction***

Recycling of agro-wastes in building material can minimize several issues such as environmental pollution, natural resource destruction, and energy utilization. This viable solution also provides an economical option and green building establishment. The manufacturing of bricks using agro-wastes is processed using industrial stages of characterization, mechanical mixing, molding, pressing, drying, firing, and testing. Eliche-Quesada and Leite-Costa [13] investigated the recycling of olive pomace bottom ash as raw materials for manufacturing lightweight and eco-friendly clay bricks. Their study [13] depicted that the bulk density and compressive strength were 1635 kg/m^3 and 33.9 MPa, respectively, for the addition of 10 wt% of olive pomace bottom ash. Moreover, the thermal conductivity reduced by 14.4%, compared to bricks obtained by only clay (control) [13]. Their work [13] suggested that the prepared bricks could offer enhanced thermal insulation of constructions.

Binici and Aksogan [7] investigated the application of olive seeds waste for the manufacturing of economical and environment-friendly insulation material. The agricultural waste was mixed with plaster, ground PVC, water, wood chips, and epoxy to produce samples having 0.97–1.33 g/cm^3 unit weight, 10–25% water absorption ratio, 0.015–0.035 km/s ultrasonic penetration speed, 0.074–0.145 W/mK thermal conductivity coefficient, 0.23–0.57 MPa compressive strength, and 0.055–0.097 MPa flexure strength [7].

Sutcu et al. [43] studied the application of olive mill waste for the manufacturing of clay bricks. Their results [43] demonstrated that 10 wt% of agricultural waste attained physical properties of 32.2% water absorption, 1.45 g/cm^3 bulk density, and 2.72 g/cm^3 apparent density at 850 °C firing temperature, compared to 17.0%, 1.84 g/cm^3, and 2.69 g/cm^3, respectively, for the control (only clay).

Aprianti et al. [3] presented the possible application of agricultural wastes such as wood waste ash, wheat straw ash, corn cob ash, rice husk ash, bamboo leaf ash, and sugarcane bagasse ash for the manufacturing of concrete. These materials can be used as a cementitious admixture to modify the compressive strength, durability, and performance of concrete, as well as, to reduce the cost of construction.

2. ***Composting***

Composting is a convenient scheme that can be used to recycle beneficial matters from agricultural waste. In this process, biological activities are controlled under aerobic environment to convert organic materials using microorganisms such as bacteria, protozoa, algae, and fungi into more stable and nutritional-rich substances [32]. The obtained stable humus-like product is recognized as compost. Compost is used to improve the properties, stability, organic/nutrient content, and texture of the soil, as well as, it can protect soil against pests and chemical imbalances. Moreover, compost is used to reduce the volume of agricultural waste, so that less amount of waste is conveyed and disposed of (e.g., incineration and landfilling). The preprocessing steps of composting include collection, transportation, removal of unwanted materials (e.g., metal, glass, and wood), size reduction by shredding, and adjustment of environmental conditions (e.g., C/N ratio, temperature, O_2 supply, mixing, and pH) [5]. The composting reaction can be described by Eq. 17.5.

$$\text{Organic fraction of waste} + O_2 \rightarrow \text{compost} + CO_2 + H_2O + NO_3^{-} + SO_4^{2-} + \text{new cells} + \text{heat} \quad (17.5)$$

Manure comprises a large amount of ammoniacal N, leading to the generation of NH_3 and NO_x through nitrification and denitrification processes. Billen et al. [6] suggested the application of poultry manure for obtaining CO_2 neutral and zero-waste electricity via fluidized bed combustion. The remained ash after combustion can be recycled as a soil conditioner due to the presence of phosphorus and potassium macronutrients [6]. Qasim et al. [32] depicted that poultry manure could be mixed with wood shaving and sawdust (1:1) in a closed reactor system with an aeration rate of 0.25 L/min/kg organic matter to obtain a non-toxic, stable, and odor-less compost. The formed composting manure could be used as an animal-based fertilizer for the maturation of crops [32]. Benabderrahim et al. [5] demonstrated that date palm (*Phoenix dactylifera* L.) was composed of cow manure at a ratio of 3:1 to form an organic fertilizer for *Medicago sativa* plants. The 30 t/ha palm-compost provided more fresh biomass, as compared with the utilization of cow manure fertilizer.

17.7 Conclusions

Most MENA countries depend on the agricultural sector as the primary source of national income, resulting in the generation of million tonnes of agricultural wastes per year. In this chapter, agricultural wastes are viewed as a renewable, environmental-friendly, and non-conventional resource, which should be appropriately managed. The three R's agricultural waste can be summarized as follows:

The reduction in agricultural wastes is achieved by several strategies such as (a) establishment of efficient sprinklers, smart irrigation controllers, evapotranspiration monitoring, and soil moisture sensors, (b) decrease the dependence on freshwater resources for irrigation including rainwater harvesting, sewage water recycling, and desalination strategies, (c) improve the irrigation methods, (d) reduce the dependence on chemical NPK fertilizers, and alternatively co-add organic fertilizers, (e) use water and soil assessment models to predict water losses from excess irrigation, (f) develop wireless sensor technologies to monitor the environmental factors affecting water utilization in farmlands, (g) apply strategic plans for investments in agricultural water management, and (h) improve the perception and awareness of population toward the environmental crisis.

The reuse of agricultural wastes include (a) use of treated agricultural wastewater for crop irrigation under strict regulations, (b) application of animal manure to improve the soil fertility, structure stability, and physical condition, (c) obtain CH_4 gas via anaerobic digestion, (d) acquire biochar, bio-oil, and gas products via pyrolysis, (e) attain energy via direct combustion, (f) use of agricultural wastes as an alternative supplement for animal feed, and (g) use of agro-wastes as an adsorbent material for the removal of various types of aquatic and toxic pollutants.

The recycling approaches of agricultural wastes include (a) application in civil construction and building material, and (b) conversion of organic compounds using microorganisms into more stable and nutritional-rich substances via composting.

17.8 Recommendations

This chapter realized several recommendations that could be employed to promote sustainable agricultural waste management in the MENA region:

(a) Identify, develop, and state the national policy and legislation that implement the ideas of agricultural waste management in ways to attain acceptable standards for public health.
(b) Organize feasible frameworks for addressing waste production minimization, waste collection, segregation, and treatment, materials recovery and reclamation, and conversion of residues to marketable products.
(c) Stakeholders, operators, and managers should be trained to have sufficient knowledge about the source and composition of agricultural wastes, and then their responsibilities and duties are monitored and regulated.
(d) Prepare suitable disposal sites that must be licensed and controlled by municipal and regulatory authorities.
(e) Develop educational programmes to enhance public awareness of environmental risk and regulation of agricultural waste disposal.
(f) Decision makers should participate with public interest teams to sum up the positive and negative impacts of the environmental aspects of the three R's agricultural waste approach.
(g) Involvement of waste generators, financing agencies, formal and informal organizations, and waste processors to establish sustainable waste management decisions that provide satisfaction to social needs.

(h) Undertake capacity building to improve agricultural waste management by supporting technology transfer, adaptation, and application.
(i) Aid for long-term investment in agricultural waste management systems regarding economic, cultural, and social situations.

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Chapter 18
Integrated Systems for Management and Utilization of Agriculture Wastes in Some MENA Regions

Hassan M. El Shaer

Abstract Natural resources in the Middle East and North Africa (MENA) region base for agriculture are very fragile. Many countries in MENA region are suffering from a shortage of raw materials which are very necessary for agriculture activities, animal feed as well as industrial purposes. They are characterized by high population growth, erratic weather conditions, limited area of arable lands, with some of the biggest and harshest deserts and with acute water shortage at present. Water resources in many countries in the region are dwindling both in quantity and in quality as consequences of climate change. Exploitation of non-conventional resources such as agriculture wastes or residues for economic agricultural and industrial products is increasingly needed. Many countries in the region have realized, in the last decade, the advantages of agricultural residues (AGRs) on the economy, industry, and environment. Such renewable materials could be generated from the recycling of agriculture wastes or residues. Agricultural residues (AGRs) are the secondary product of agricultural activities such as vegetative parts left after harvesting vegetables, fruit tree pruning and wastes from food processing and agro-industries by-products. This chapter aims at casting lights on potential management and usages of common agriculture residues (wastes) in some countries in the MENA region. It focuses on identification of potential AGR and common utilization technologies. Constraints and strategies for management and utilization are also discussed. It is concluded that most of these residues are either burned in the field which has a negative impact on the environment or utilized in inefficient ways as a fuel, animal feeds, and composting. These agricultural residues when fully exploited would be expected to foster the development of small-scale agro-industries, create new job opportunities, and provide new arable lands. Most important is that the utilization of AGR to substitute forage crops for animal feed could save millions of hectares of lands that could be devoted for food production for human consumption, reduce the imports of wheat and other strategic crops. Thus reduce reliance on importation which improves food security, in addition to saving millions of dollars spent on importation of strategic materials. The AGRs are expected to play an important role in bridging the food gap in many countries in MENA region and improve the livelihood of the rural farmers.

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Some AGR technologies are developed and reached the implementation stage; others are at R&D and reached the pilot stage. Unfortunately, data are incomplete for some MENA region countries. There is a necessity to work out a strategy at both national and regional levels to foster the utilization of AGR and to encourage the collaboration of the leading countries for better utilization.

Keywords Environment · Organic waste · Recycling · By-products · MENA region · Aridity · Agriculture · Animal · Technologies

18.1 Introduction

The Middle East and North Africa (MENA) region is an economically diverse region that includes both the oil-rich economies in the Gulf and countries that are resource-scarce in relation to population. Increases in human population, disposable income, and urbanization in MENA countries "are driving an unprecedented rise in demand for foods of animal origin that will stretch the capacity of existing production and distribution systems." It is obvious that agriculture plays an important role in the economies of most of the countries in the MENA region. The contribution of the agricultural sector to the overall economy varies significantly among countries in the region (from about 3.2% in Saudi Arabia to 13.4% in Egypt), FAO [1]. However, aridity, difficult terrain, and harsh climatic conditions in the region make it one of the least productive agricultural regions in the world. Large quantities of agriculture residues (AGR) such as field crop residues and agro-industrial by-products are produced annually and are vastly underutilized. The term agricultural residue is used in a broad sense to include wastes from agriculture, food, and agro-industries. They consist of utilized residues from growing and processing of raw agricultural products. It is important to mention that, the need for food to cope with the increased population, the limited and exhausted available lands and climate change impact necessitate a rational utilization of such AGR at least for those countries requiring simple technologies and low initial investment cost. Many countries in the region are suffering from a shortage of raw materials which are very necessary for agriculture and industrial purposes. Such renewable materials could be generated from the recycling of AGR. For instances, utilization of AGR as compost may contribute to the expansion of arable lands through its use for reclamation of soil, saving fresh water and reducing irrigation requirements [2, 3]. Moreover, when AGRs are used as animal feeds, it will improve animal production and decrease the cost of animal products [4–6].

The report of FAO/RNE [7] on agricultural residues in the region revealed that there is more than 440 million tons of AGR on dry matter weight basis. Pakistan, Turkey, Iran, and Egypt have the highest quantities of AGR available in the region. The same study reported that the total amount of AGR available in the whole Arab world amounted to 155 million tons representing 35% of the total AGR in the region. Egypt is the highest in AGR production in the Arab world. However, most of these residues are not fully explored; the AGRs are either burned in the field or utilized humbly for animal feeds, charcoal, and composting production [4, 8]. AGR could have an essential role in bridging the food gap in many MENA region countries when is fully exploited. AGR potentially could be utilized for several agriculture and industrial materials production in rural and peri-urban areas [9]. The chapter focuses on classification, advantages of the utilization AGR in the MENA region, general constraints encountering utilization and common management approaches and technologies for utilization. The proposed strategies for utilization of AGR are, also, briefed.

18.2 Main Natural Resources Features of the Middle East and North Africa (MENA)

The Middle East and North Africa (MENA) region includes: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, West Bank and Gaza, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen. In other meaning, the MENA region represents a large zone extending from Morocco in northwest Africa to Iran in southwest Asia. It generally includes all Middle East Asian and North African countries, as well as Iran. Oil is the main natural resource that the region has with 70% of the world reserves with 797 billion barrels (8 of the 12 countries of OPEC are in the MENA region). It is characterized by high population growth and erratic weather conditions, limited area of arable lands, with fragile natural resources base for agriculture, acute water shortage at present coupled with potential water conflicts in the future.

On the environmental front, the region is characterized by an arid or semiarid climate and one of the lowest rates of availability of water in the world. Approximately "15 of the 20 countries in the world living below the poverty line in water (water stress situation: less than 1000 m^3 per year per person) are in the MENA region" [10]. Water is scarce and will become even more. Climate change, population growth, changes in consumption habits, and the pursued development model—all exacerbate local water shortages. Even though MENA region is the most water-scarce and dry region worldwide, many countries across the region are highly dependent on agriculture where agriculture constitutes a vital role in the economies of most of the countries. Consequently, large quantities of agriculture residues (AGRs) such as field crop residues and agro-industrial by-products are produced annually and are vastly underutilized.

18.2.1 Agricultural Residues Definition and Classification

Agricultural residues (AGRs) are the secondary products of most of the agricultural activities such as vegetative parts left after harvesting vegetables, fruit tree pruning, and wastes from food processing. We can add to the above the agro-industries plants that include; stalks, stovers, straws, bagasse, or beet molasses, hulls, oil filtered cakes, fruit and vegetable residues, and fruit trees pruning, date palm and date residues. Agro-industries wastes such as tomato and potato wastes, rice bran, hulls, husks, and cottonseeds are important components of AGR.

The AGRs have several defections and classifications depending on the original sources, types, etc. It may be, in common, classified differently according to the source of their extraction as follows:

1. Fields and gardens (e.g., residues of seasonal field crops and products of pruning of fruit trees).
2. Food and agro-industrial wastes (including agricultural fiber processing plants; bagasse in sugar mills, tomato and potato wastes, rice hulls and husks and cottonseeds extraction and other oil processing plants, etc.).
3. Fruit and vegetable markets (refused low quality of fruits and vegetables).
4. Municipal wastes; household, restaurants, and hotel organic residues.

The concerned AGRs in this chapter include field crops, fruit residues (pruning, harvesting, processing, packing, etc.), landscaping residues, and agro-industrial wastes. These AGR materials are expected to be increased markedly during the coming decades as a result of increased food production to keep pace with the growing population in the region [1, 10]. For example, date crop production has increased in all countries in the region during the last 15 years except Morocco. On the other hand as another example, date crop production has increased from 40 to 300% in UAE. A similar increase of the AGRs will be foreseen for other field crops residues and agro-industrial by-products (AIBP).

In other words, agricultural residues biomass is defined as any plant matter being used directly or/and indirectly after specific processing treatments or technologies in agriculture and industrial purposes. These biomass resources in the MENA region could be classified into three categories:

- Primary residues: which include agricultural crops (crops, vegetal waste, straw, etc.) and forests (wood, tops, branches, etc.);
- Secondary residues: which include food processing residues (e.g., bagasse, tillage), fiber processing residues and animal excreta (dung, chicken litter, etc.);
- Tertiary residues: which include municipal waste produced by the residential, commercial, and public services and collected by local authorities.

The major biomass produced in MENA countries stressed in this study is primary and secondary residues which are mostly used in Turkey, Sudan, Egypt, Iran, Algeria, Saudi Arabia, Syria, and Jordan. Traditionally, biomass energy has been widely used in rural areas for domestic purposes in the MENA region. Crop residues encompass all agricultural wastes such as bagasse, straw, stem, stalk, leaves, husk, shell, peel, pulp, and stubble. The current farming practice is usually to plough these residues back into the soil, burn them, or leave to be decomposed or grazed by livestock.

18.2.2 Primary Residues

Primary agriculture residues vary among the MENA countries. For instances, wheat is the major crop in the MENA region followed by coarse grains (cereal grains other than wheat and rice). Both wheat and coarse grains constitute approximately 70% of the total agricultural crops produced. Large quantities of crop residues produced annually are vastly underutilized. Turkey is the major producer of agricultural crops in the region (approximately 40%) followed by Egypt and Iran. The majority of such crops are consumed as food in most of the MENA countries. Apart from Turkey, most MENA countries have to import their needs of wheat, rice, and sugar [1]. Coarse grains are usually used as feed for the livestock. Sugarcane industry is very well established in Sudan and presents a promising potential for biomass projects (cogeneration or use of bagasse for electricity production). The Sudanese government is promoting the sugar industry, encouraging the establishment of small-scale factories, and is planning to increase export volume. Comparing the MENA region to other regions in the world, the MENA has slightly lower agricultural land compared to the world average and significantly lower compared to USA, EU-15, and sub-Saharan Africa. This is due mainly to the arid/semiarid nature of the region as well as water scarcity [6, 10].

18.2.3 Secondary Residues

Such residues include food processing residues, fiber processing residues, and animal excreta. MENA region has a strong animal population, in particular, sheep, goats, dairy cattle, chicken, and camels, playing an important role in the national economies. There is a wide range of animal wastes that can be used as sources of secondary biomass. The most common sources are animal and poultry manures. The animal population is more concentrated in North Africa (48% of MENA total animal population). Sudan, Iran, and Turkey are the richest MENA countries in terms of animal population. Also, the food industry in MENA produces a large number of organic residues and by-products that can be used as biomass energy sources. In recent decades, the fast-growing food and beverage processing industry have remarkably increased in importance in major countries of the MENA. Since the early 1990s, the increased agricultural output stimulated an increase in fruit and vegetable canning as well as juice, beverage, and oil processing in countries like Egypt, Syria, Morocco, Tunisia, Lebanon, and Saudi Arabia [10].

Table 18.1 Amounts of crop residues and fruit trees pruning produced annually in some MENA Regional Countries (million tons dry weight, El-Mously, 2002) Type/residue

	Egypt	Iran	Morocco	Sudan	Pakistan	Tunisia	Turkey	Total
Field crop residues	71.5	41.0	14.0	17.2	144.9	4.0	109.4	402.0
Fruit trees pruning	2.7	2.7	1.0	0.3	1.3	0.6	3.4	12.0
Total	74.2	43.7	15.0	17.5	146.2	4.6	112.8	414.0

18.3 Quantity of Agriculture Residues (AGRs) in Some MENA Countries

Agricultural residues are generated in huge amounts annually and differ in type and characteristics. Most of 440 million tons of AGR are from sugarcane, wheat, rice, sugar beet, and tomato [1]. In a study by FAO/MENA, El-Mously (2002) estimated the agricultural residues coming from 28 countries of the Near East region at 459 million tons/dry weight/year, agriculture residues coming from the countries Egypt, Iran, Morocco, Pakistan, Sudan, Tunisia, and Turkey are amounted approximately 414 million tons/year. The amount of these residues coming from each country is presented in Table 18.1.

18.4 Technologies and Utilization of Agricultural Residues

Most of the agriculture residues are either burned in the field or utilized in an inefficient way as a fuel, animal feeds, production of charcoal, or composting. However, the utilization of agricultural residues is not fully explored. These agricultural residues when fully exploited could have an essential role in bridging the food gap in many countries in the region. Recent studies and country reports revealed that traditional utilization of agriculture residues (AGRs) is confined to direct burning in the field or in houses, which has a negative impact on the environment. At least ten main technologies for utilization of agricultural residues have been identified in MENA region. These technologies are used at different stages of development, i.e., some technologies are developed and applied, others are at a pilot stage, and some are still under research and development [11].

The most important and common ones are defined by as follows:

1. Structural use (roofing, walls, wall paneling, building material, gypsum-fiberboards).
2. New industrial materials: used in construction and woodworking industries as substitutes for wood (oriental stand board, particleboard, plywood, block board, etc.).

3. Chemical industrial producing products substituting wood and/or plastics (fiberboard, pulp, wood plastic composites, fiber-reinforced plastics, bioplastics).
4. Furniture items, interior fittings, and parquet.
5. Light goods and utensils (mashrabiah, stationery items, packing material, and packages).
6. Fermentation products (yeast, ethanol, vinegar, etc.).
7. Fodder usage.
8. Mushroom production and animal bedding.
9. Soil conditioning and fertilizers products, e.g., composted with conventional and organic products.
10. Fuel and energy (charcoal, electricity, biogas).

The beneficial technologies for utilization of AGR could be summarized as follows:

1. ***Utilizing rice straw or rice husks for manufacturing bricks***
   Various percentages of a mixture of either loam and sand or cement and sand are utilized for producing bricks after the addition of variable amounts of 1–2 mm in length of rice straw or rice husks then dried. Some of the resulted bricks of loam (Tafla) were burned to produce burned (or red) bricks while bricks of the cement are kept without burning [12, 13]. The bricks included rice waste have good quality and seemed to have lighter weight than nonwaste additive bricks.
2. ***Production of silica gel***
   Production of silica gel silicates from the rice hulls and straws is very promising. El Mahdy et al. [14] reported that it has been widely used in edible oil refining and frying oil treatment as an alternative to caustic soda addition, as pharmaceutical products, detergents, adhesives, chromatographic techniques, and ceramics. The produced silica gel not only alleviates the problem's associated with rice hull or straw disposal but also generates a high-profit margin, value-added product and creating a profitable new industry in rural localities in Egypt.
3. ***Wood production***
   Utilization of AGR for the production of woods, as substitutes for the imported wood, would save millions of dollars, also, provides new avenues of the investments. Wood has some accordance in chemical analysis with some AGR. For instances, Abo-Hegazi [13] reported that rice straw contains from 46 to 59% cellulose, 11–15% lignin, 21–25% pentosan but that of wheat contains 48–57% cellulose, 16–17% lignin, 28% pentosan, and barley straw contains 44–49% cellulose, 16–19% lignin, 23–32% pentosan. Bagasse content of the same materials is: 46, 20, and 25%, respectively. Corn stalks contain 38, 34, and 20% from the same materials, respectively. Wood, in general, contains approximately 58–67% cellulose, 20–34% lignin, and 11–27% pentosan. Panelboard, MDF, and HDF woods can be produced by getting rid of some substances (such as leaves which have a very low content of cell fibers and a high content of silicates), then appropriate binders and small amounts of additives such as paraffin wax combined with pressure under heating followed by trimming of the resulted boards [13].

Properties of MDF and HDF were almost similar to that originated from wood wastes or bagasse.

4. ***Organic growing media production***
The use of compacted rice straw bales as an organic growing media in greenhouses and open field production is a new approach in Egypt. It has been developed to control soil born pests and diseases as well as weeds instead of methyl bromide. Greenhouse trials were successfully carried out using this technique to produce better fruit quality and higher yields of cucumber, pepper cantaloupe, and strawberries. The application of these methods in the open field provides the opportunity in particular for the utilization in the new agriculture desert areas to produce high-quality crops and to promote organic cultivation. The organic, recycled materials could be used as a cultivation media or an alternative to peat moss that has to be imported [2].
5. ***Compost production***
Composting is a method of converting AGR into dried, non-odoriferous, through aerobic bacterial activities, fertilizer. **AGR** can be composted and used to replace a significant part of the mineral nitrogen fertilization with nitrogen recovery of 6−22% [2, 3]. Compost provides the plant with required nutrients and provides the soil with nitrogen, phosphorus and potassium, trace elements and humus. Compost improves the physical and chemical properties of the soil. It increases its water holding capacity and the cation-exchange capacity as well [3]. The long-term compost applications improved the nitrogen status of the soil over the years [15].
6. ***Bio-ethanol***
Recently bio-ethanol is a world demand to overcome the depletion of fossil fuels and their ever increasing prices. Also, it minimizes the global warming, creates job, and increases welfare for the rural community through a better lifestyle. Ethanol is an oxygenated fuel that contains 35% oxygen, which reduces NO_x emissions from combustion. Some of AGR resources can either be used directly as an untreated material for microbial growth or be used by appropriate treatment with enzymes for bioenergy production. The products generated from perishable wastes can be in liquid or gaseous forms of biofuels [16]. Among various wastes used for ethanol production, potato peels, apple pomace, waste apples [17], banana peel, banana waste, beet waste, beet pomace, and peach wastes have shown encouraging results [18].
7. ***BioGas***
Biogas is the result of microbial degradation of lignocelluloses materials (i.e., agriculture residues, animal excreta, mushroom spent) under anaerobic conditions in a liquid medium. Many systems have been developed to produce biogas such as the Chinese and Indian models. Small- and large-scale digesters made of polyethylene have been developed [19], El-Shimi (2004). The main product is biogas which is used for heat, cooking, light and/or electricity generation in rural areas. Another product is the slurry which contains sludge that could be dried and pulverized and used as a soil fertilizer [2] or could be used as a part of feed ingredients at a ratio of 30% for small ruminants [19]. Biogas manure is

free from the offensive odor normally associated with manure pits/heaps. Parasites normally present are also killed during the process of digestion. Biogas can be used to power internal combustion engines and to substitute for diesel oil in small electric generators.

8. ***Charcoal production***
   Charcoal is a carbonaceous solid with a fixed carbon content of 70% or more. It is usually manufactured from hardwoods or other dense biomass by paralysis. Charcoal is used as a fuel for heating and barbecue. It is also employed as a reductant for metal ores and other industrial purposes. In the developed countries, efficient processes are employed for charcoal production in big industrial kilns, retorts, and portable steel kilns. Meanwhile in the developing world, inefficient processes are widely used for charcoal production [12]. Because of pollution associated with the inefficient conversion of biomass to charcoal, this charcoal fuel cycle is among the most greenhouse-gas-intensive energy source employed by mankind. Traditionally, in Egypt, such inefficient process is widely spread in the rural areas. Nowadays a new efficient process is highly recommended to be developed for solving such problems [20].
9. ***Mushroom production***
   Straws, wood, and animal manure have been used for mushroom production. Mushroom has very nutritious food ingredient. It has high protein content on a dry weight basis as compared with other food (El-Shimi 2004). Major mushroom varieties are *Agaricus* (button mushroom), heat-loving mushroom *Volvariella volvacea* (straw mushroom), and *Pleurotussajor-caju* (oyster mushroom). The two latter mushrooms can be grown on AGR and do not require strict controlled growing conditions [21]. Hassan [22] reported that mushrooms (*P. ostreatus and A. bisporus*) protein contains all essential amino acids totaling 26–28/100 g protein. The limiting amino acids in mushrooms are methionine and cysteine, while lysine is the dominant amino acids in almost mushroom types. Thus, mushrooms considered an ideal supplement for another lysine—deficit protein such as cereal protein [22]. The spent is the major residues of mushroom production; it is the material remaining after harvesting mushroom that can be used for (1) Upgrading animal feed, (2) A substrate to generate biogas, (3) A substrate for paper manufacture, (4) A substrate for Agaricus mushroom, and (5) A substrate to increase soil fertility due to humic and folic acids content.
10. ***Animal and poultry feed production***
    Most of such AGR are considered good quality feeds since it might be offered to animals directly or after special processing methods to improve their utilization and economic value. Green AGR can be directly used as fodder for animals. Dried residues, e.g., hulls of rice, *faba beans*, *lentils*, *soybean*, *ground nuts*, cottonseed, and sunflower seeds can be added at the rate of 5% of the ration of livestock [4, 6, 23]. Pulverized straws of wheat, sugarcane, maize, all vegetable and fruit residues are also used as feed; wheat bran can be used up to 20% safely. Approaches for improving the feeding value of AGR can be summarized in the following:

(a) Physical and mechanical methods such as grinding, crashing, and pelleting,
(b) Chemical methods as alkali hydrolysis or ammonia or urea treatments, etc.,
(c) Biological methods (fungi, bacteria) or anaerobic fermentation method (ensiling),
(d) The use of substances which regulate the rumenal digestive processes,
(e) Feed block processing method and,
(f) Combinations of the above.

However, the treatments used for upgrading the quality of the AGR as feed materials and the research approaches need to consider the potentiality of adoption by the farmers. The most common processing methods in MENA region are:

1. ***Silage***: Silage is an anaerobic fermentation process where fresh AGR would be ensiled with other feed ingredients in a silo. The ensiling process has many advantages, mainly to improve the nutritive value and consumption of the ensiled materials as well as save this feed for a critical time, particularly during the feed shortage [24]. For instances, ensiling rice straw (whether treated or not) with berseem (*Trifolium alexandirnium)* resulted in a clear improvement in the performance and daily live weight gain of fattening sheep [4, 23, 25].
2. ***Ammoniation with ammonia or urea***: Ammoniation of AGR with ammonia or urea is an important process to increase the protein contents and to improve the feed consumption and nutritive values of agriculture residues, in particular, the crop residues [26, 27]. The reaction must take place in a closed environment; it may take 8 weeks in winter and less in summer [28].
3. ***Feed blocks***: Feed blocks are a solidified mixture of agro-industrial by-products and other field crops mixed with some other feed ingredients. They are considered as catalyst supplement allowing the balanced supply of nutrients, e.g., energy, nitrogen, minerals, and vitamins [29, 30]. The majority of fruit and vegetable wastes like tomato pomace, bottle gourd pomace, citrus pulp, carrot pulp, baby corn husk and forage, cabbage and pea pods, pineapple waste, olive cake, date seeds, and pineapple bran are highly fermentable and perishable, mainly because of high moisture, total soluble sugars, and crude protein contents. There are no standard formulas for blocks since ingredients choice is related to available substrates and local means of farmers. Nevertheless, some specific characteristics of ingredients are to be considered in relation to their respective roles (physical and/or nutritional). In most of cases, blocks include urea, molasses, a binding agent (cement, clay, lime…), a fibrous substrate, and salt. Some other products such as minerals, some by-products, drugs are some times added [4].
4. ***Physical and dehydration treatments***: Grinding and/or pelleting and dehydration lead to a reduction in particle size and density. Grinding led to an increase of 25% in the voluntary intake, of 98% in daily live weight gain, and of 36% improvement in conversion efficiency [4, 25]. A study was conducted, in KSA, to evaluate the chemical composition and nutritive value of some selected AGR to be used as animal feeds and to evaluate the effect of dehydration treatments on their chemical and microbiological analysis [5]. Five types of AGR were collected, then converted to air-dried material, and after being heated to evaluate

the impact of heating on the chemical analyses and microbiological parameters [25]. These AGR materials were namely: 1—Landscape mowing grasses (LMG), 2—Mixed ornamental plants residues (MOPR), 3—Olive trees pruning (OTP), 4—Citrus tree pruning (CTP), 5—Date trees pruning(DTP), 6—Horse stable grasses residues (HSGR), and 7—Greenhouses by-products (GHBP). The results (Table 18.2) indicated that all AGR feed ingredients appeared to be nutritious since they contained enough concentration of nutrients to cover animal nutritional requirements. Crude protein content varied among the feed ingredients and ranged from 6.53% (CTP) to 18.77% (LMG). Heating treatment, generally, did not affect ($P > 0.05$) all nutrients concentration nor microbiological parameters of all tested feed ingredients.

18.5 Novel Value-Added Products from Fruit and Vegetable Wastes

In general, the residues of fruit and vegetable processing industries wastes could be utilized for: (a) biogas production, (b) drying and used as poultry feed, (c) used as compost, (d) fermented by the method of solid-state fermentation to produce citric acid and ethanol. The losses of raw materials as solid wastes during the different processing treatments of vegetable and fruits vary considerably from crop to crop, (as shown in Table 18.3). Such figures should be taken into considerations for evaluation of the AGR wastes for management and utilization.

The most novel value-added products from fruit and vegetable wastes could be summarized as follows:

1. ***Essential oils***
   The citrus peels are a potential source of essential oil (EO) and yield 0.5–3.0 kg oil/tonnes of fruit [31]. Citrus EO is widely used in alcoholic beverages, confectioneries, soft drinks, perfumes, soaps, cosmetics, and household products owing to its aromatic flavor. It also serves as a masking agent in pharmaceutical products [32]. Oils from both sweet and bitter oranges are used in tea formulations and as an ingredient in stomachic, carminative, and laxative preparations. Lemon EO contains D-limonene, which improves the immunity, counters occasional feelings of depression, promotes clarity of thought and purpose, energizes and stimulates the mind and body, opens and releases emotional blocks and supports skin health and reduces the appearance of wrinkles [33].
2. ***Edible oils***
   The fat in mango seed kernel is a promising source of edible oil, Guava (*Psidiumguajava*L., Myrtaceae) seeds, usually discarded during processing of juice and pulp, contain 5–13% oil rich in essential fatty acids [34]. The passion fruit seed oil is rich in unsaturated fatty acids (87.6%) and has free radical scavenging activity [35].

Table 18.2 Proximate chemical composition (% on dry matter basis) and microbiological parameters of five AGR affected by dehydration treatments

Parameters	Air-dried AGR					Heated AGR				
	LMG	MOPR	HSGR	OTP	OTPOF	LMG	MOPR	HSGR	OTP	OTPOF
Dry matter	91.40^{ab}	90.19^{ab}	96.48^{a}	87.51^{ab}	91.83^{ab}	98.92^{a}	97.10^{a}	98.60^{a}	99.44^{a}	97.45^{a}
Crude protein	19.77^{a}	12.72^{b}	12.76^{b}	10.58^{bc}	8.81^{bc}	20.10^{a}	13.64^{b}	12.79^{b}	10.88^{bc}	9.63^{bc}
Crude fiber	22.40^{b}	20.74^{b}	35.65^{a}	17.25^{c}	28.35^{ab}	24.61^{b}	22.66^{b}	34.07^{a}	21.42^{b}	27.50^{ab}
Ether Extract	2.18^{a}	1.71^{ab}	1.00^{c}	1.76^{ab}	1.44^{bc}	1.50^{b}	1.22^{bc}	1.32^{b}	1.67^{ab}	1.72^{a}
Organic matter	86.89^{ab}	83.26^{ab}	89.78^{a}	92.69^{a}	93.55^{a}	86.78^{ab}	80.16^{b}	88.45^{ab}	91.10^{a}	89.50^{a}
Ash	13.11^{b}	16.74^{a}	10.22^{b}	7.31^{c}	6.45^{c}	13.22^{b}	19.84^{a}	11.55^{b}	8.90^{c}	10.50^{b}
NFE	42.54^{c}	48.09^{ab}	40.37^{c}	63.10^{a}	54.95^{a}	40.57^{b}	42.64^{b}	40.27^{b}	57.13^{a}	50.56^{ab}
Aflatoxins	ND[d]	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total coliform count	1.2×10^{6}	1.1×10^{5}	2.6×10^{6}	2.8×10^{5}	2.7×10^{4}	2.2×10^{4}	7.0×10^{3}	4.1×10^{4}	1.8×10^{3}	9.5×10^{2}
Fecal coliform count	3.0×10	8.0×10	5.0×10	1.0×10	<10	1.0×10	3.0×10	<10	<10	<10
Yeast & mold count	2.6×10^{6}	4.3×10^{6}	3.1×10^{6}	4.8×10^{6}	6.0×10^{5}	3.3×10^{4}	3.7×10^{4}	5.3×10^{4}	2.4×10^{4}	8.4×10^{3}
Salmonella spp, cfu/gm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Staph aureus, cfu/gm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bacillus cereus, cfu/gm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clostridium spp, cfu/gm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

a, b, c; means with different letters in the same row differ significantly ($P < 0.05$), otherwise no significant differences, [d]ND: Not Detected

Table 18.3 Losses of raw materials as solid wastes (percentage) during canning of fruits and vegetables (El-Nawawy 1996)

Commodity	Edible materials	Total solid residue
Apples	35	12–55
Apricots	25	8
Asparagus	3	30–41
Green beans	5	12–20
Lima beans	6	85
Beets	7	25–40
Carrots	18	33–52
Corn	20	72–86
Grapefruit	58	3
Peaches	40	11–20
Pears	42	12–46
Peas	6	8–79
Spinach	10	40
Tomatoes	5	25

3. ***Pigments***
   "Tomato peel is a rich source of carotenoids such as lycopene" [36]. It may be beneficial in curing cancer, coronary heart disease, and other chronic conditions. The addition of tomato peel to meat products can result in a healthier product due to both the lycopene and fiber present "in this by-product of tomato processing. Carrot pomace is also a good source of carotenoids" [37]. Anthocyanin pigments in banana bracts (leaves below calyx) and beetroot pulp were evaluated for their potential application as natural food colorants.
4. ***Single Cell Protein***
   Single cell proteins can be produced from dried and pectin extracted apple pomace by using *Trichoderma viride* and *Aspergillus niger*. The grape waste and pressed apple pulp have also been used as a substrate for *Aspergillus niger* to generate crude protein and cellulose. Pineapple waste for production of single cell protein production has also been utilized. Citrus peel juice has also been used to generate single cell protein using *Fusarium*. Potato peels supplemented with ammonium chloride have also been used for the production of protein by using a non-toxic fungi *pleurotus ostreatus*.

18.6 Integrated Approach for the Utilization of Agriculture Residues

Agriculture residues should be utilized and recycled in an integrated approach, i.e., AGR can be utilized, and the end product is used; the residues can be further utilized. For example, all agriculture wastes generated from farming animals and field crop residues and fruit and vegetable residues could be utilized and recycled in an integrated approach to produce: food for human, feed for an animal, compost for soil and energy; in addition to various other products such as wood, paper, …etc. The most common integrated approaches or systems (integrated models) are indicated in the following figure:

Four integrated recycling models could be produced from AGR at farm levels. They are:

1. ***Mushroom system***
   Mushroom is grown on straw. After harvesting the mushroom, the spent (the remaining straw after harvesting) is further used to: (a) grow Agaricus mushroom, (b) supplement to animal feed, (c) substrate for biogas production, (d) substrate for cardboard/paper manufacture, (e) soil conditioner…etc.
   The mushroom system can produce: ***food + animal feed + organic fertilizer***
2. ***Biogas system***
   Biogas system can produce ***energy + organic fertilizer + animal feed + water for irrigation***.
   In the biogas process, two main products are produced: (a) the gas (biogas) can be used for heat, light, electricity, and (b) the biogas manure (effluent) can be dried and used as fertilizer or as a feed ingredient for ruminants [23].
   The integrated mushroom and biogas system to produce: ***Energy + food + feed + organic fertilizer***.
3. **Integrated farming animal and field crops**
   This model could produce ***Food + feed + energy***.
   Most of the agriculture residues such as sugarcane and sugar beet could be integrated together with animal excreta to be converted into food, in addition to animal feed which will allow animals to grow and produce various animal products while animal excreta is utilized as (a) source for biogas, (b) compost, and (c) possibly as a feed ingredient (not more than 30% of the total ration for ruminants).
4. ***Compost system***
   Compost system could produce: ***animal feed + organic fertilizers***
   AR converted into compost which is added into the soil to enrich it with macro- and micronutrients which will be absorbed by plants (+residues) to be fed by animals.

18.7 General Constraints Encountering Management and Utilization of AGR

The tremendous increase in the quantum and diversity of waste materials generated by human activities has focused the spotlight on waste disposal methods. Generally, the greater the economic prosperity and the higher percentage of urban population, the greater the amount of waste produced [10]. Reduction in the volume and mass of wastes is a crucial issue due to limited availability of final disposal sites in almost all parts of the world. There is, no doubt, an obvious need to reduce, reuse, and recycle agriculture wastes to solve such problems. Several problems that could limit the utilization of AGR include the following:

- The bulkiness of by-products, seasonal availability of AGR, and their availability in scattered areas which make its collection and transportation cumbersome.
- Poor infrastructure and the high cost of transportation.
- Lack of database about quantities seasonality, availability, location, type of AGR, and method of utilization and institution involved
- Lack of research programs and strategies for utilization of these residues.
- Lack of experience in a special AGR utilization technology which impedes its production.
- Lack of cooperation between local institutions and communities in a country on the one hand and industry and research base specialized in AGR utilization on the other hand.
- Lack of cooperation between countries which permits transfer of information and technologies from one country to the other.
- Inadequate national scientific R&D to generate technologies of AGR utilization to be adopted.

18.8 Benefits, Significances, and Economic of Agricultural Residues Utilization

It is worth mentioning that recent concerns about increased cost and reduced availability of fossil fuels, feed, food, and other raw materials, improved human nutrition, and environmental degradation have prompted scientists to re-evaluate the current agricultural—by-products management and utilization. The awareness of the economic value of AGR is increasing nowadays all over the world. The benefits that can be derived from the utilization of agricultural residues would be:

1. Provide an opportunity for the new clean environment-friendly source of energy.
2. Fostering organic agriculture thus promote agriculture products exportation.
3. Reduce lands used for fodder production, thus provide more land for food production.
4. Creation of new small agro-industries in the rural and peri-urban areas.
5. Utilization of the available AGR for fiberboard woods production instead of importation.
6. Creation of new job opportunities particularly for women in the rural areas.
7. Reducing the costs of animal and poultry feedstuffs thus increasing animal and poultry products at reasonable prices.
8. Manufacture of bio-fertilizers at economical costs.

The significances of agricultural residues could be briefed in the following points:

- They are available in most rural areas which means that all local communities have their own share in these residues and future activities.
- The AGRs are annually renewable material resources and are reasonably cheap.
- The AGRs are easily accessible as they do not need sophisticated equipment for their extraction.
- There is a base for innovative technologies for utilization of these residues stemmed from the familiarity with accumulated knowledge and technical heritage on available AGR.
- The economic use of AGR preserves the environment by eliminating the use of pesticides to combat against rodents and pests (e.g., cotton pink worm).
- The attention of public, private sectors and research institutions to AGR could inspire the innovation and development of endogenous knowledge of local communities in rural areas.

Concerning the economic return on investment in AGR utilization, it was estimated that approximately 1.3–1.6 Gtonnes of food is lost or wasted globally every year, which is estimated to have enormous environmental (ca 3.3 Gtonnes of CO_2 eq. greenhouse gas emission/year, 305 km^3 water/year, 1.5 billion ha land to grow food that is wasted), social (936 billion US$), and economic (1055 billion US$) costs FAO [38]. Also, the food loss and waste have an impact on food security, natural resource availability, and local and national economies.

On the other hand, burning waste field crops is one of the main causes of environmental pollution. Such problems should be alleviated by raising economic interest in the recycling of these "waste" materials to generate extra income for the farmers. However, as mentioned previously, several commodities or products would be generated from different models of AGR utilization such as:

- Compost for organic agriculture
- Clean energy in the form of methane gas generated in biogas plants
- Animal feed
- Food in the form of mushroom
- Wood, charcoal, active carbon, etc.
- Ethanol, bakers and fodder yeasts and CO_2 and other chemicals
- Bales of straw for building
- Paper pulp
- Substitute for cement in building operations.

Moreover, by demonstrating the added economic benefits of utilizing agriculture waste materials, economic modernization and diversification could be promoted to reduce poverty by offering an added income-earning opportunity to local farmers [38]. However, utilization of such AGR materials should reduce the need to import more expensive food, feed, bio-fuel, and building materials [13]. The economic and environmental benefits derived from recycling and utilization of AGR can help to offset high costs of fuel, fertilizers, animal feeds, etc., in addition to alleviating the pollution problems. These economic benefits could show a promising approach for recycling AGR. However, as mentioned previously, several commodities or products would be generated from different models of AGR utilization such as: compost, clean energy animal and poultry feed, food (mushroom), wood, charcoal, active carbon, ethanol, bakers and fodder yeasts and CO_2 and other chemicals, bales of straw for building, paper pulp, substitute for cement in building operations [4, 8, 9, 11].

The economic return of investments in AGR utilization is varied and depending on the type of AGR conversion and its products. Results showed that for every one Egyptian Pound (LE) invested in compost, 2.8 LE are gained. In case of biogas, every one pound invested gained 3.15 LE. For silage, every pound invested gained 20–28 LE [8]. However, the most common example for processing AGR technologies in many MENA countries is utilization of AGR as compost may contribute to expansion of arable lands through its use for reclamation of soil (provides new lands), and reduce irrigation requirements. When AGRs are used, also, for animal feed, it will improve animal production, decrease the cost of animal products, and conserve land and water which can be devoted for cereal production for a human.

18.9 Capabilities of Various MENA Countries to Utilize AGR

Given the different technologies cited before, the capabilities of the countries: Egypt, Iran, Morocco, Pakistan, Sudan, Tunisia, and Turkey to utilize AGR were evaluated through literature and correspondence. Results are presented in Table 18.4. Countries are at different levels of AGR utilization. Some technologies are developed and reached the implementation stage; others are at R&D and reached the pilot stage. Unfortunately, data are incomplete for some countries.

18.10 Proposed Strategies for AGR Utilization in MENA Regions

There is a necessity to work out a strategy at both national and regional levels to foster the utilization of AGRs and to encourage the collaboration of the leading countries for better utilization. The following elements may help in developing the strategies required:

1. Transfer and implement existing technologies of AGRs utilization from leading countries where the technology is established.
2. Strengthening the existing centers in each country to build in scientific and technological capabilities for utilization of AGRs through three approaches:

Table 18.4 Technologies applied in agricultural residues utilization in certain countries of MENA region

Technology	Egypt	Iran	Morocco	Sudan	Pakistan	Turkey	Tunisia
Feed:							
Direct use	+	+	+	+	+	+	
Silage	+		+	+		+	
Urea	+	+	+	+			+
Ammonia	+	+		+			+
Feed block	+	+	+	+			
Molasses	+	+	+	+			
Food:							
Mushroom	+	+				+	
Agro-industries:							
Card board	+	+			+	+	
Pulp, paper	+	+		R	+		
Building block	R	+			+	R	
Active carbon	R	+					
Wood:							
Panels	P					R	
Lumber-like	P					R	
MDF, HDF, LDF	P			R			
Particleboard	+				+	+	
Furniture	+					+	
Animal bedding:			+				
Compost:	+				+		
Energy:							
Direct use	+	+		+	+		
Biogas	+		R	R	+		R
Charcoal	+	+					
Briquette	R			RP			
Fermentation:							
Molasses	+	+	+	+	+		
Alcohol	+	+	+	P	+		
Vinegar	+	+			+		
Fodder yeast	+	+	+				
Bakers yeast	+	+			+		

R Research
R Pilot
+ Means present

- Dissemination of established technologies among private sector and training concerned personnel in AGRs availability and utilization.
- Increase public awareness about utilization of AGRs handling and utilization.
- Establish Web site for AGRs production, consumption, and utilization.

3. The governments should adopt short-, medium-, and long-term policies to ensure sustainability of AGRs utilization.
4. Establishment of the database for AGRs to compile information on AGRs available; quantities, type, seasons and current methods of utilization and disposal, institution involved in R&D and those engaged in implementation.
5. Facing and solving constraints in the utilization of AGRs in rural areas in the region.

18.11 Conclusions

The natural resources of the MENA region are degraded and fragile. Many of the region countries have high AGR production which may be considered as valuable renewable materials for agriculture and industrial purposes. These residues represent a part of great investments made in agricultural activities, in terms of capital, water, and human effort. It could provide the material base of a new industrial revolution that could emerge from rural areas in the developing countries in MENA region countries. The rediscovery of agricultural residues as local cheap renewable materials should inspire imagination and innovations for the development of local communities and building of endogenous scientific and technical capabilities along the path of applied research on the industrial use of these materials. Adopting proper technologies for utilization of AGR could save hundred millions of US dollars through reducing the imports of fertilizers, animal and poultry feeds, wood, paper, etc. since these materials could be produced from agriculture residues recycling. Some AGR technologies are developed and reached the implementation stage; others are at R&D and reached pilot stage. Unfortunately, data are incomplete for some MENA region countries and should be collected for further future development.

18.12 Recommendations

The chapter recommended the important following points:

1. Establishment of database and a network for AGR at national and regional levels to compile information on AGR available; quantities, type, seasons and current methods of utilization and disposal, institution involved in research and development(R&D) and those engaged in implementation.
2. Rehabilitate and update existing technologies that suffer from negligence and lack of proper equipments and spare parts, maintenance…etc.

3. Encourage the private sectors and industrial institutions to introduce new technologies of AGR utilization.
4. Enhance the establishment of small industries to absorb entrepreneurs from men and women and increase job opportunities in the region

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Chapter 19
Renewable Energy, a Clean Environment and Solar Desalination

Raad H. S. Al Jibouri and Shawn Buckley

Abstract Renewable energy has been competing against fossil fuels for seven decades. Every 30 years or so, the costs associated with fossil fuels become high and renewable energy has become economic once again. Now fossil fuels are warming the planet and renewable energy could help the impact. Improvements in photovoltaic (PV) efficiency along with improved production have cut costs. Costs and production methods have also impacted solar thermal energy use. Heat from the sun is captured by reflecting surfaces that reduce losses. Solar thermal has become cost competitive with PV, especially when short-term storage (4–24 h) is required. Here, we look at the details of both solar thermal generally and solar desalination specifically. The Middle East North Africa (MENA) region is well suited to solar thermal applications because low humidity provides the region with high direct sunshine. Little is lost to light reflected by water molecules in the atmosphere. We look at the economics of various solar methods using the levelized cost of energy (LCOE). It is the sensitivity of LCOE to other system parameters such as power capacity, investment, and power generation that identifies the best ways to capture solar energy economically. Finally, the specific example of desalination is used to illustrate the differences between various solar options. Photovoltaic collection and reverse osmosis are compared in terms of capital cost and energy cost to concentrated solar thermal collection and multi-effect distillation. These two have the lowest capital costs and LCOE among the options available today.

Keywords Concentrated solar power · Photovoltaic · Reverse osmosis · Multiple effect distillation · Desalination · Levelized cost of energy · Solar economics

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19.1 Introduction

Waste generation is a continuous process in nature to renew life. It is inherent in human activity. Waste is solid, liquid, or gaseous. In this chapter, we will focus mainly on wastes from all human activity, such as household waste organic waste, and those wastes resulting from manufacturing, mechanization, agriculture, transportation, and other processes.

We will also focus on treating any waste to convert it from one form to another, either to neutralize its harm to the person and the surrounding environment, or to convert it to other useful types of materials that can be recycled and reused, to generate energy or for any other purpose. It is obvious that this treatment, regardless of its type, origin, or composition, indeed requires work, or energy. This energy must be clean and renewable, and this is precisely the subject of this chapter.

Energy and Work
Since the beginning of life, energy has been an essential factor in human life, helping people to live, contributing to their development and increasing their well-being. It has become in the last centuries and decades the nucleus of civilization, and one of the most important measures of progress and advancement of societies. Energy, as we live in its details today, comes to us today, using fuel we get from two main sources:

- Fossil fuel energy: gas, oil, coal, that derive from living organisms buried millions of years ago.
- Renewable fuel energy: sun, wind, biomass, geothermal, hydro, waterfalls, waves, that derive from renewable sources, ones that aren't used up.

The main traditional source of energy is fossil fuels, and despite the progress in the exploration and reserves, large and important in the field of traditional energy, types, and quantities of reserves, which has occurred in the last two centuries from natural sources. However, the increasing need for them and the increase in the diversity of their use, as well as the excessive use of them, lead to the acceleration of depletion in several tens of years.

Additionally, it has a severe damage to the environment and its direct and indirect negative impact on the daily life of the environment as well as its effect climate on the planet.

For these and other reasons, scientists and specialists sought to find new sources of energy provided they are sustainable and called renewable energy or green energy because they do not harm the environment, especially humans, plants, and other organisms.

Physics tells us that **Energy** is the ability to do **Work**. Energy will not be destroyed or created from nothing, but it can be transformed from one form to another. Mechanical energy, for example, can turn into electrical energy, Energy of chemical reactions to kinetic or thermal energy.

In this chapter, we will try to answer these important and vital questions: "**What is the most appropriate energy that we would prefer to use in waste treatment? How can we continue to secure it? What is its cost?**"

It makes sense that we must have a number of basic conditions for using the energy required for waste treatment operations. They are supposed to be:

- Clean energy does not cause further damage to the environment.
- Sources are available in geographical areas where they are consumed.
- Be renewable and inexhaustible.
- Can be generated at the lowest possible cost.
- Be scalable: It can work on the production of processing units of different sizes, including small or medium, to ensure distribution in areas close to areas of these wastes to reduce the cost of transport for long distances, and the associated consumption of more fossil fuels, which in turn cause more pollution of the environment.
- Distributed deliberately, according to strict controls to prevent any collateral damage that may result from this distribution.

We are always obliged to comply with these standards and any other criteria we have not mentioned, regardless of the method or technique of waste treatment that needs energy. Other techniques include (1) burning waste in a closed space to generate biogas, (2) using the heat generated by the burning of fossil fuels such as petroleum products or coal, (3) electric arcs that use electric power to heat treatment furnaces, or generate plasma … and others.

Certainly, energy from renewable sources is the solution, but that alone may not be an adequate answer. Our analysis should be more profound, and we should identify the most environmentally and economically appropriate source in each country or geographical area, especially Egypt, discussed in the following paragraphs.

19.2 Types of Renewable Energy

There are several sources of renewable energy, including what is widespread in the world such as the sun, wind, and waves. A second type of less widespread energy in specific areas is geothermal, waterfalls, and hydropower sources. A third type does not exist naturally such as biogas generated from waste and agricultural crops. In any case, the availability of a particular type of renewable energy in a geographical area, as well as its relatively low cost, determine the feasibility of its use and spread, which can be placed within two main points, for example:

- Its presence in the surrounding area geographically, for example, the availability of waterfalls in the cold and rainy areas such as mountains and waterfalls, and lack of desert environments. Another example is the abundance of wind in deserts and oceans, and its absence in the valleys and the slopes of the mountains opposite to the direction of the prevailing wind that act as windbreakers.

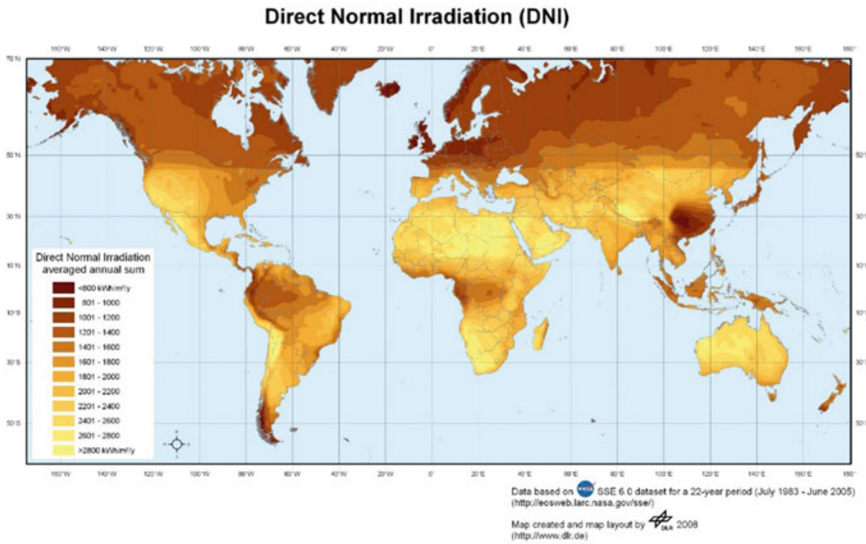

Fig. 19.1 Global DNI map

- The cost of using and obtaining the energy source and the efficiency of converting it to other types of energy required is assumed to be competitive with other alternatives. That is, whether they are from fossil or renewable sources if they provide more than one source of renewable energy in a region, such as the sun, wind, hydropower.
- Here, economic feasibility criteria govern the selection of the most suitable for use, Fig. 19.1 [18] shows that the Middle East and North Africa region is located within the so-called solar belt, with abundant solar irradiation. Other geographical areas are scattered and relatively far from the main landmass, like Chile, parts of the USA, Australia, and South Africa.

What kind of energy source is most abundant in the earth? To have a clearer idea of the sizes of these sources and how to resolve the answer about which is the best one for the MENA region see Fig. 19.2 [17]. Using this data, we can choose the appropriate technology to take advantage of them. We notice that all the small boxes shown represent fossil fuel sources and its reserves in earth and environment, and the number of years they could run out when consumed at current rates of demand to cover global energy consumption. In contrast, the large box containing all the boxes represents the solar energy that reaches earth annually. The tiny box, located in the far corner at the bottom right of the image represents the sum of energy consumed by the world each year. By comparing their respective sizes to others, we can have an initial idea of how much energy the sun can provide our planet.

The total amount of solar energy reaching Earth per year is equivalent to hundreds of times all the Earth's reserves of renewable and non-renewable energy sources combined over the past tens of thousands of years as we have seen in Fig. 19.2. The

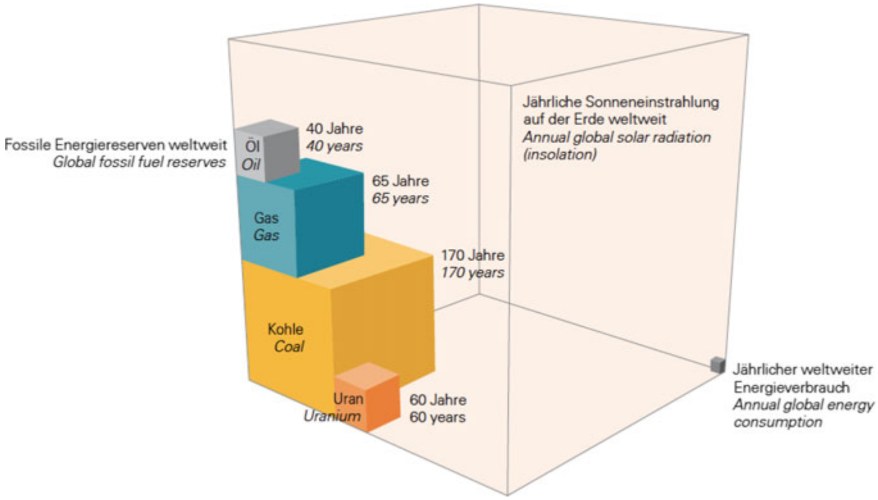

Fig. 19.2 Energy sources and its reserves

sun is the major reservoir of energy sources. We should put it front of our attention; solar energy must be the main choice.

However, here is an important question: "**Is solar energy the most feasible option compared to other types of renewable energy in the MENA region?**".

The most abundant source of renewable energies on earth is solar energy. With most of the other energy sources (renewable or non-renewable), it was the sun that was responsible for their existence in one form or another. Solar energy covers the majority of the earth's surface, and the only differences between regions are the number of hours the sun shines during the seasons and the angle the solar radiation makes as it falls on the surface of the Earth. The direct normal irradiation or DNI measures the geographical quantity of the sun's energy. DNI is the average amount of solar energy per square meter of land measured in kW/m^2 units.

Figure 19.3 shows satellite images showing annual energy harvesting rates for five types of renewable energies, including solar, in MENA region [19]. Dark color (black) represents the density or abundance of the energy of a given type. Biomass is abundant in Europe with its rainy climate, but not in the MENA region. Geothermal, coming from mountain-building is also abundant in Europe but not in the MENA region. Hydropower is plentiful in Europe with its high mountains, but not in the MEAN region. However, both wind energy and solar are much more abundant in MENA regions than most of Europe. Of these two, solar energy is much more abundant than any of the other types.

Solar Light Energy

This energy is collected from sunlight by special electronic cells called photovoltaic cells (PV). When light falls on its surface, light particles (photons) stimulate electrons from the cell material and give enough energy to free it from the force of attraction

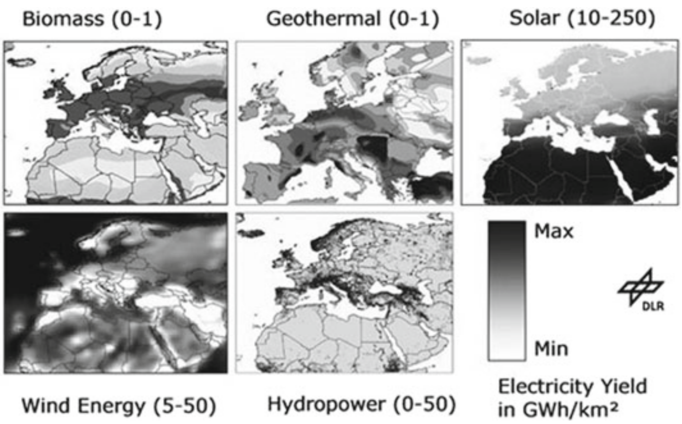

Fig. 19.3 Main energy sources in MENA countries

to the cell. This helps the electrons to flow enough to generate an electrical current inside the cells and produce a current under the influence of the resulting voltage difference. Then collect the current from a large number of these cells located within a panel, arrange a number of these panels in larger groups, to generate electricity in the quantities required.

Note that the current generated by this process is constant over time and is called direct current (DC). It is similar to the current in batteries that power a flashlight: it does not change over time. However, we find that most of the electricity used in public electricity networks uses a second type of electricity called alternating current (AC). In AC networks, the current changes its direction over a certain period.

Therefore, one of the main components in photovoltaic power plants is the presence of a device called an inverter that converts the DC current to AC current. Inverter devices within the PV panels generation system reduce the overall efficiency of the system. Also, the inverter needs maintenance and its lifetime is less than one-third of the power plant lifetime. It must be replaced periodically which increases the operating expenses of the system [12].

Other systems and types of these PV cells are made with a different design than those used in conventional or commercial panels. The light striking these specialized PV cells is concentrated by mirrors that increases the energy available to convert to electricity. It is called concentrated PV (CPV). However, while fewer PV cells are required by the concentration, ultimately the result is the same, we need to change DC to AC with an inverter.

The PV panel technique is generally appropriate for countries where the annual rate of direct normal irradiation (DNI) is less than 2000 kW/m^2, according to DLR experts, although we have other opinions that it could be less, possibly as low as 1400 kW/m^2. These countries have a lower percentage of Direct Normal Irradiation (DNI) but a higher percentage of **diffuse** irradiation at their higher humidity. Photovoltaic panels can use both the direct and the diffuse giving them an advantage in these regions. Irrespective of the value of 1400 or 2000, most MENA countries have much higher DNI sometimes as high as 3000 kW/m^2 (see Fig. 19.3). This is one of the most important reasons for the low efficiency of solar PV systems, in addition to the short its lifetime.

Also, these PV panels efficiencies are strongly affected by the appearance of clouds in the sky, dust, and high temperature in the MENA countries, high ambient temperature is particularly degrading since PV panels lose efficiency as ambient temperature increases [3]

All these reasons make PV less useful in the MENA region.

Solar Thermal Energy

The second type of solar energy is thermal. By concentrating solar energy with mirrors, the DNI increases its efficiency in a technique called the concentrated solar thermal (CST) or concentrated solar power (CSP). The difference between solar light energy and solar thermal energy is that solar light energy converts only the visible light in the sun's radiation to electricity. The light portion represents only 43% of the total solar energy spectrum. By contrast, solar thermal energy includes both the visible and the invisible light in the sun's spectrum. The invisible portion is called infra-red (IR); it contains 52% of the solar spectrum.

Combining the visible and invisible portions of the spectrum means 95% of the sun's spectrum could be captured as thermal energy as shown in Fig. 19.4. Thus, solar thermal has twice the energy available as those obtained from the light only [14].

Concentrating solar energy is done by several techniques. The four main types are solar tower, parabolic trough, dish Sterling, Fresnel mirrors.

The main distinguishing feature of concentrated solar thermal energy is:

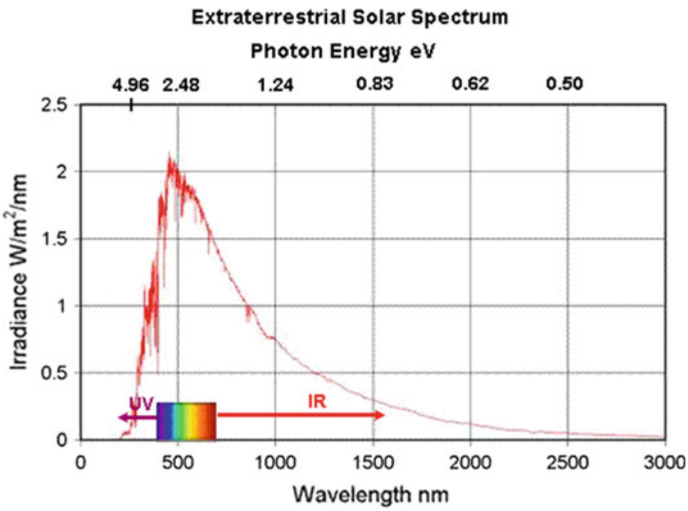

Fig. 19.4 Solar irradiation spectrum

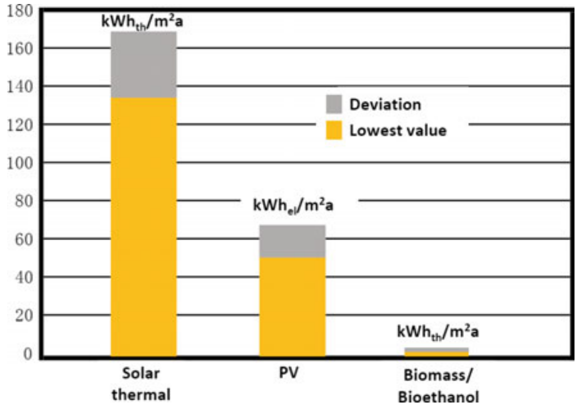

Fig. 19.5 Solar thermal shows highest energy yield per square meter. *Source* Fraunhofer ISE, PlanEnergi and Chalmers University

- The land area needed by this energy per square meter is three times less than photovoltaic solar PV. It may reach about 40 times as compared to other technologies, such as wind and biofuels (Fig. 19.5) [10].
- The possibility of storing thermal energy at a much lower cost than electric storage, by batteries or the like, and the maintenance and operation effort is less.
- The number of electricity generation hours daily from thermal energy more than light energy, where it can work 24 h a day, as well as the possibility of storage of excess thermal energy used as a reserve to generate electricity at night, or in the absence of the sun during the day as a result of clouds and storms.
- The cost of producing electrical kW-h is one of the most important criteria for the efficiency of the system and its economic feasibility. It is inversely proportional to the possible number of daily hours of generation as shown in Fig. 19.7.
- The electrical energy generated by the conversion of thermal energy is alternating current (AC) and can be used directly by the electrical network and by AC devices and appliances. But when generated from the light energy is direct current (DC) and must first be converted to AC increasing the investment cost, reducing the efficiency and usefulness of the generation system's economic feasibility [24].

Heat capture and its concentration is an essential part of the CSP system. Its low-cost storage capability has other applications without the direct generation of electricity. These applications include air conditioning (heating/cooling), dairy industry, refrigerated and frozen warehouses, desalination and purification of water, poultry and bird farming, heavy-oil extraction operations from oil wells among others. More than 60% of the energy consumption in the industry is used to generate heat [20].

Concentrated solar thermal energy is more efficient and economically more feasible than photovoltaic energy for many reasons. It can also be the appropriate lever for advancing most of the sustainable development goals (SDGs) announced by the United Nations directly and effectively.

As previously mentioned, we can confidently say that concentrated solar thermal power is the preferred option for the Middle East and North Africa region, including Egypt, as it is already one of the best regions in the world, which we will try to explain later, by expanding some important details about solar energy specifically.

Over the last ten years, many articles, studies, research, and conferences have been published, all focusing on the possibility of generating most of the human energy needs of solar energy exclusively. Some of them went so far as to suggest specific geographical regions, primarily Egypt. The first economic and technical feasibility of electrical power generation projects cover most of the needs of Europe, the Middle East, and Africa. Some of these studies have been characterized by efficient effort, advanced standards and advanced scientific and technical outlook. The best example of this is the study funded by the European Union for Project (REACCESS) "Risk of Energy Availability: Common Corridors for Europe Supply Security." [11].

In the years that followed, there has been a lot of modernization and development in concentrated solar thermal technologies such as heat storage solutions for solar thermal collecting and its concentrating systems and redesign of system parts. The cost of fabrication and installation of CSP systems has also been significantly reduced, making it the most suitable option for electricity generation in the MENA region and will inevitably reflect any new approaches to the project, if it is re-examined and implemented now. While PV solar panels may be used as a minor part of the project, concentrated solar thermal techniques should be the backbone of the project.

19.3 CSP Is the Most Suitable Option in the MENA Regions

World Bank study released in 2010 [27], states that the Middle East and North Africa would take the solar thermal option. Figure 19.6 shows the best-suited places on the world map where the concentrated solar thermal energy exists. Many of these regions are located within the MENA region. The importance of this map is clearly illustrated by the fact that this region is geographically located in the heart of the world. It covers and links three continents: Asia, Africa, and Europe. It reduces the cost of transporting energy among them and makes them more feasible economically and technical.

How Can We Start …?

- The discussion about main renewable energy source used in public utility electricity generation should be ended in most Arab countries, namely, solar energy, as we have shown above. With the exception of region-specific exceptions of another renewable source such as biogas from agricultural waste in rural areas. These exceptions are controlled by more specific factors related to climate, environment, infrastructure, and economic feasibility.
- Adopting one main source of two types of photovoltaic or thermal solar energy, in favor of the thermal, since most of the Arab region is ready for this type. But with

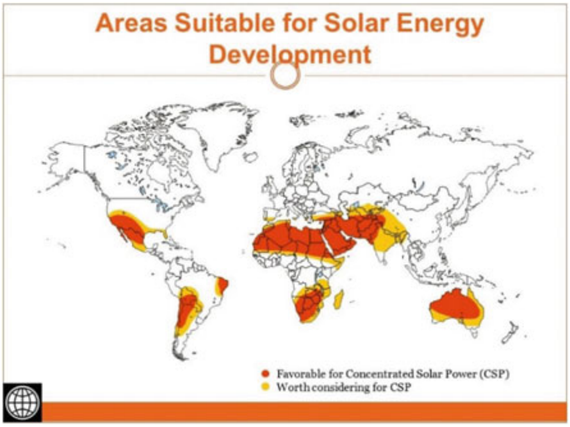

Fig. 19.6 Areas suitable or solar energy development

the possibility of using light as a source in specific places and conditions require a limited amount of energy such as lighting lamps in roads or supplying electricity to a rural house.

- Determine the trade-off in the main technologies that need to be applied, taking into consideration the use of others under case-by-case study, including available technologies such as solar tower, parabolic trough, Fresnel mirrors and so forth. With continuous follow-up and testing of any new technology that is likely to be invented later, to evaluate and introduce them in comparison with previous techniques.

19.4 Energy Economics Issue

The economic issue of energy is one of the most important engines of trade and progress in the world, and the importance of energy has caused a conflict of influence and even wars. What we are interested in here is the cost of energy to the consumer. This cost is mainly determined by the cost of fuel-to-energy generation/conversion systems (e.g., dams, nuclear reactors … etc.). Also, reliability is important including operation costs, management, and maintenance. Another important factor is the type and cost of fuel used in these systems to generate the required energy. The greatest proportion of fuel currently used in power generation consists of fossil fuels such as coal, petroleum, and gas. Moreover, it is burned to generate the necessary heat to operate equipment and machines that convert it into other types of energy required.

All fossil fuels have been on the earth for thousands of years. The extraction and consumption process is a one-way process—the process of exhausting all reserves if its consumption continues at current rates. Also, its consumption has always caused serious damage to the main elements of the environment in which human beings live—human, animal, and plant—as well as the climate, water, and soil of the earth.

Here, we must pause at a common and important term, the levelized cost of energy (LCOE) cost. LCOE represents the cost of producing power units such as electric power that computes the cost of producing kW or MW of energy. All energy producers from renewable or traditional sources are keen to reflect a positive image of the efficiency of their energy systems, announcing that the LCOE cost of production is lower than other technologies or companies. The LCOE is given by Eq. (19.1):

$$\text{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electricity produced over lifetime}} \tag{19.1}$$

By returning to the term LCOE, we can put its definition in a simple formula [22], by calculating all the money spent on the power station from building, operating, maintenance, management, and other costs for the lifetime of the power station (typically set at 25 years) divided by all energy produced over the life of the station. Our calculations consider the real value of money with time or the discount rate (r). Put into one equation, the formula is written below:

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{19.2}$$

where:

$\mathbf{I_t}$ Investment at year *t*.
$\mathbf{M_t}$ Management, maintenance, and operation expenditures at year *t*.
$\mathbf{F_t}$ Fuel cost at year *t*.
$\mathbf{E_t}$ Energy generated at year *t*.
t Year number.
n Lifetime of the power plant.
r Discount rate.

In most cases of renewable power plants, the value of fuel F_t is zero as in solar energy. Other cases have a low cost as in other types of renewable energies such as syngas technology. As a measure of comparison, the cost of producing electricity from fossil fuels is about $45 per megawatt. This means that the closer the LCOE value is to or below this figure, the source energy can be a good alternative and a strong competitor to the fossil fuel energy.

The low value of this factor is usually considered to be a measure of the low cost of electricity production and therefore competitive. Therefore, companies that use and develop a renewable energy technology promote the technologies they market, by the value of LCOE as a fundamental criterion in proving the efficiency and feasibility of their technologies. We think this is not entirely true and does not reflect a real image economically. We may find two offers from two companies, the first using CSP and the second company using PV technology. The investment needed to build a generating plant using CSP technology could be four times greater investment than that using PV, and yet both produce a kW-h with seven cents [23].

However, we must remember that the PV station works just 4–5 h a day while the CSP station supplies electricity for 16–24 h a day. With a reserve of thermal storage, it could deliver electricity for several more hours, despite the absence of the sun due to clouds or dust storms depending on this reserve. This example makes us think about reconsidering the LCOE calculation to reflect clearly the effect of the number of hours of production and producing power.

In this regard, we conducted a comparative study on the impact of three key factors in the construction of power plant: the value of the main investment, the plant's capacity, and finally the number of generating hours with the help of energy storage. We followed a specific methodology by changing only one factor at a time and fixing the other variables. We also assumed a strictly selected standard value. We then increased the value by 20% each time until we reached a value of 100%. In the opposite direction, we reduced the standard value by 10% each time to zero, and then we calculated the value of the LCOE factor for the lifetime of the station at each value. We repeated the process on the other factors that we mentioned above to determine the sensitivity and chart diagram, and the result obtained as shown in the curves shown in Fig. 19.7, which we publish for the first time.

On the first curve (top), we note that the value of the LCOE obtained by the change in the amount of capacity of the station is almost negligible, where it is almost linear (close to straight). In the middle graph, we notice that when the value of the investment (or power station cost). The graph's behavior of the LCOE is directly proportional. If we want to reduce the value of LCOE means that the value of the investment should be reduced and vice versa. As for the third case shown (bottom), the relationship between the factor LCOE and the number of hour/day for the producing electricity, the relationship is inversely proportional. That is, increasing hours of electricity generation leads to reducing the value of LCOE factor, which is always required. The mean target is to have a value of LCOE equal to or less than its value in conventional power stations using fossil fuel. The logical conclusion is that if we want a good economic benefit by reducing the value of LCOE, we should focus on how to increase the number of hours per day to generate more electricity.

19.5 Using Solar Energy for Water Desalination

In MENA countries, better water could improve the economics of a large portion of the population. Desalination is used here as an example of how CSP energy can be used. Other applications include air cooling, domestic hot water heating, ice making, food processing, fabric processing, and enhanced oil recovery.

Several different desalination processes are available in arid countries to desalinate water. Historically, thermal processes have included both the multistage flash distillation (MSF) developed in Kuwait in the 1950s and multi-effect distillation

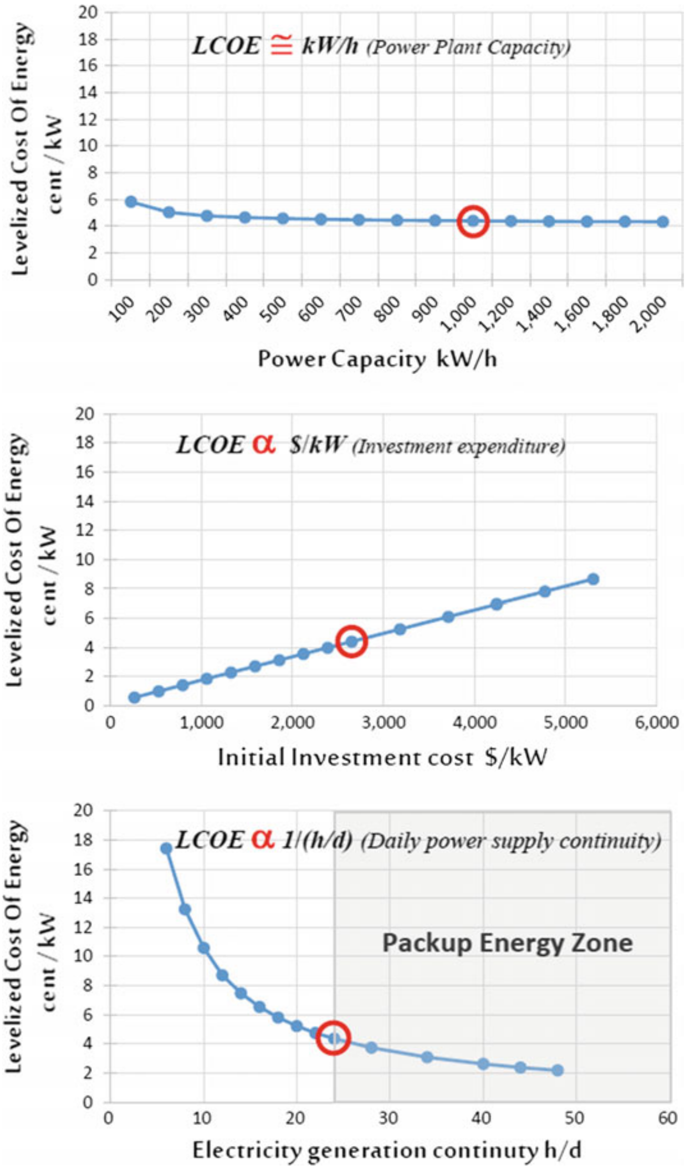

Fig. 19.7 LCOE sensitivity for power capacity, investment, and power generation

(MED) pioneered by Saudi Arabia in the 1930s. In the last several decades, reverse osmosis (RO) has been developed to compete with these thermal processes.

Thermal processes MSF and MED compete well in "locations where energy costs are low." [6, p. 20]. This is because RO desalinates by forcing water through membranes that separate the salty or brackish water from clean water. The membranes operate at high pressures, needing pumps that use electrical power. Electrical power is usually a scarce commodity in arid communities, making RO a reliable method of desalination in wealthy, technological countries like Israel or the USA. However, because RO is electricity intensive, it is not well suited to less developed countries.

Renewable energy could be used to power desalination in arid countries because these countries have abundant solar resources. MENA countries typically have two or three times the solar energy as humid climates [21]. However, clean water is a scarce commodity in these climates. Can solar energy be made more efficient for desalination in these arid climates?

The question is how best to apply solar energy to desalination. One possibility is an "electrical" solution: photovoltaic solar panels power RO pumps that make clean water. Another possibility is using solar thermal techniques with thermal desalination processes. Which one makes the most economic sense? Which one produces the most cubic meters of clean water for the least capital cost? Which one has the lowest operating costs?

First consider the capital cost of the two approaches: equipment, land, construction costs, interest, insurance, and other costs. Industry studies show that MED is the least expensive investment cost of the thermal processes (MSF 1200–1500 $/(m^3/day), MED 900–1500 $/(m^3/day) [7]. By contrast, photovoltaic/reverse osmosis (PV/RO) is slightly less at $700–$900 $/(m^3/day).

Second, consider the efficiency of the two approaches. In PV installations, sunlight that falls onto the PV wafers is converted directly to electricity. Most installed PV systems get 15–20% efficiency (ratio of energy captured to the solar energy that falls on its collectors). By comparison, thermal systems capture 60–70% of the solar energy that falls on their collectors.

$$\textbf{Thermal MED}: \text{Efficiency} = 60-70\%$$
$$\textbf{Thermal MSF}: \text{Efficiency} = 60-70\%$$
$$\textbf{PV/RO}: \text{Efficiency} = 15-20\%$$

Why the big difference? Most PV collectors are not designed to capture both heat and electricity. In PV, the other 80–85% of the sun's heat is simply rejected to the environment. By contrast, thermal collectors try to capture as much of the solar heat available as possible. Even at elevated temperatures, by careful thermal design, thermal collectors lose far less energy to the environment. By contrast, PV collectors try to lose heat to keep their wafers cool for higher conversion efficiency.

From a global warming perspective, thermal collectors are 3–4 times better at reducing global warming. Instead of rejecting solar thermal heat as done in PV, this heat energy is stored for other uses. Global warming researchers like to talk of "wedges": policies that cut the heat released by humans into the atmosphere. Solar thermal represents 3–4 wedges compared to the single wedge coming from solar PV.

19.6 Desalination Equipment

Given the metrics from the literature, we can estimate costs for various components of an efficient solar thermal application to produce clean water. RO cannot be easily or efficiently used with solar thermal collectors—and MSF and MED cannot be easily or efficiently used with PV panels. That means there are only two pathways: (1) THERMAL: thermal collectors with MSF or MED thermal desalination and (2) ELECTRICAL: PV collectors with RO desalination (photovoltaic/reverse osmosis).

Of these two pathways, the biggest factor is solar efficiency: a solar thermal system at 70% efficiency captures 3–4 times more solar energy than a PV/RO system that captures about 20% of the sun's energy.

Despite RO being slightly less costly than thermal processes MSF and MED, combining PV with RO (PV/RO) generates far less clean water than thermal processes.

$$\textbf{Thermal MED}\text{: Cost/Efficiency} = 1000\ \$/(\text{m}^3/\text{day})/70\% = \mathbf{1430}\ \$/(\mathbf{m^3/day})$$

$$\textbf{Thermal MSF}\text{: Cost/Efficiency} = 1500\ \$/(\text{m}^3/\text{day})/70\% = \mathbf{2140}\ \$/(\mathbf{m^3/day})$$

$$\textbf{PV/RO}\text{: Cost/Efficiency} = 900\ \$/(\text{m}^3/\text{day})/20\% = \mathbf{4500}\ \$/(\mathbf{m^3/day})$$

Then, the relative efficiency (dividing each by the highest efficiency) takes a different result:

$$\textbf{Thermal MED}\text{: Relative Efficiency} = 1430\ \$/(\text{m}^3/\text{day})/1430\ \$/(\text{m}^3/\text{day}) = \mathbf{100}\%$$

$$\textbf{Thermal MSF}\text{: Relative Efficiency} = 1430\ \$/(\text{m}^3/\text{day})/2140\ \$/(\text{m}^3/\text{day}) = \mathbf{67}\%$$

$$\textbf{PV/RO}\text{: Relative Efficiency} = 1430\ \$/(\text{m}^3/\text{day})/4500\ \$/(\text{m}^3/\text{day}) = \mathbf{32}\%$$

Using this metric, MED is clearly superior to other types of desalination; it is somewhat better than MSF and three times better than PV/RO.

However, the difference is worse than the above because solar energy is not available 24 h a day. This is a tautology, of course, but it has broad implications when analyzing the economics of using solar energy for desalination.

Most current MED plants run on waste heat from power plants. They run continuously, night and day since the heat from the power plant is available continuously. However, solar heat is only available for about a quarter of the day. The bulk of solar heat is available from 9 AM to 3 PM—6 h out of the 24 h of the day. Sure, there is some solar heat available before 9 AM and after 3 PM, but it is perhaps 10–15% of the total (shown in Fig. 19.8).

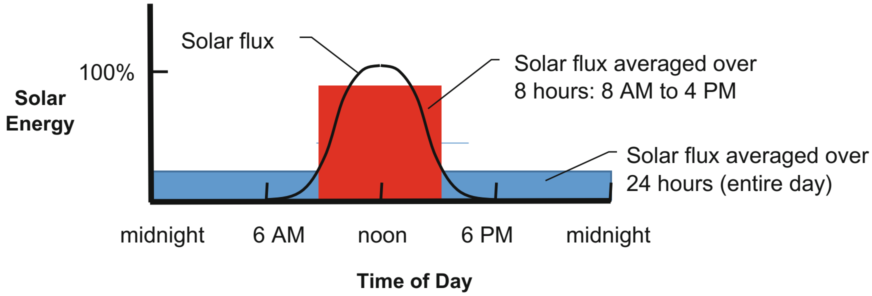

Fig. 19.8 Daily solar variation

If water were desalinated only during the 6 h of prime sunlight, the equipment would need to be 4 times larger: a 4× larger desalination plant and 4× more electrical power to run it during those choice daylight hours. At other times (e.g., near sunup, near sundown, at night or during cloudy weather), the desalination equipment would be idle.

19.7 Storage

One way to reduce the desalination equipment required is to store the daytime energy for later use. Run a one-quarter smaller desalination plant all the time instead of a large plant running only 6 h a day. That means storing energy for up to 18 h of night-time and low light periods.

Storing electricity itself is notoriously expensive, 2018 Lithium battery packs cost $400/kW-h–$750/kW-h for solar installations [9]. Large manufacturing facilities by companies like Tesla are expected to drop the cost to less than $200/kW-h. Even 5 h of electricity storage in batteries will double the cost of a typical solar PV residential installation [4].

Storing heat is much cheaper. It is called thermal energy storage (TES). Heat storage is typically either a "phase change" material or a "sensible heat" material. Phase change materials melt at a particular temperature (lithium nitrate to 250 °C, sodium nitrate and potassium nitrate mixes to 550 °C), storing heat as they freeze [5]. At these temperatures, the phase change salts are liquid and can also be used as the heat transfer material.

Sensible heat materials store heat by changing temperature over a small temperature range. For example, when a kilogram of concrete (specific heat 0.75 kJ/kg °C) changes in temperature from 200 °C to 300 °C (100 °C delta), it stores:

$$0.75\ \text{kJ}/(\text{kg}\ ^\circ\text{C}) \times 100\ ^\circ\text{C} \times \text{kW s/kJ} = 75\ \text{kW-s/kg} \times \text{h}/3600\ \text{s} = 0.02\ \text{kW-h/kg}$$

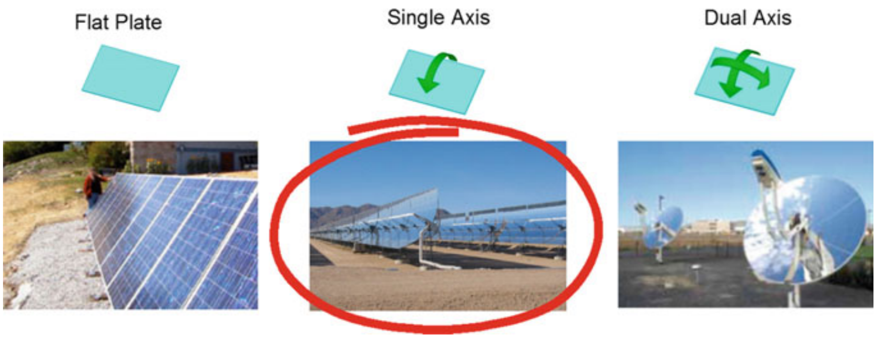

Fig. 19.9 Concentrating solar energy

Heat can be transferred in and out of storage using steel heat transfer pipes embedded into the concrete. Oils such as mineral oil pumped through the pipes act as the heat transfer fluid. German researchers have investigated concrete heat storage for solar trough collectors for decades [13]. Newer "thermal oils" such as Duratherm can be heated to 450 °C and may be more durable [8].

19.8 CSP Solar Collectors

Since thermal solar collectors are needed for thermal desalination, a review of thermal solar collectors is in order. CSP "Concentrated Solar Power" solar collectors concentrate sunlight by reflecting it into an absorber. The absorber has a heat absorbing surface that captures the concentrated solar energy efficiently—as high as 95% efficiency.

However, the absorber gets hot and can lose the heat it has captured by heat losses to the environment. To reduce heat losses, transparent covers allow solar energy through to the absorber but prevent radiation and convection losses.

CSP collectors can be categorized by the number of axes by which they track the sun. In Fig. 19.9, flat-plate collectors have no tracking (zero axes), trough and linear Fresnel collectors have single-axis tracking, and heliostat collectors track the sun using two axes.

Flat-plate collectors have a low structure cost because they are immobile. However, they typically use water as their heat transfer fluid and have low output temperatures (<100 °C). Since the collector surface is the same surface that loses heat, losses are high, even at the low temperatures at which they operate.

Two-axes tracking has dual-axis collectors or heliostats. These have a high concentration (>100×) and can heat their internal heat transfer fluid to high temperatures (500 °C). However, their structure cost is high since their mirrors must move accurately in two axes. Heliostats have been used effectively in "Power Tower" projects such as the Crescent Dunes Solar Energy Project (Tonopah, NV) [16].

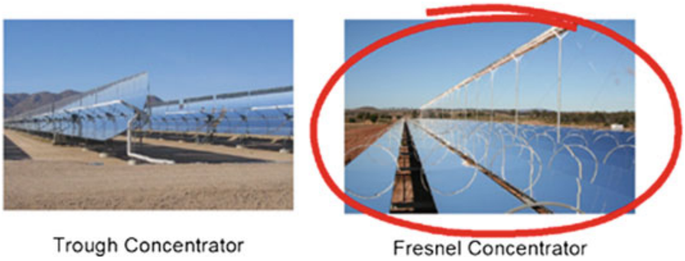

Fig. 19.10 Single-axis concentrators

Single-axis collectors are a sweet spot between the two: low in cost because of simple structures while their vacuum-jacketed absorbers produce the higher temperatures required of efficient thermodynamic engines. They have a low concentration (20× to 40×) and can heat their heat transfer oil to 300 °C.

19.9 Single-Axis Collectors

Single-axis concentrators (see Fig. 19.10) have lower heat losses than flat-plate collectors. With vacuum-jacketed absorbers, they can recover 70% or more of the solar energy falling on them. They are often called "linear" collectors because these collectors have mirrors that concentrate the solar energy into a long, narrow beam. Assembled, they produce linear strings of collectors where the absorber of each collector connects into the next collector of the string to heat its heat transfer fluid to a higher temperature.

Collectors can be deployed in two ways. One way is curving the mirrors in the shape of a parabola. These systems are called parabolic trough concentrators. The absorber is put at the focal point of the parabola where sunlight is concentrated. Trough collectors have been deployed around the world by Spanish companies Abengoa [1] and Acciona [2]. They are large systems used to compliment steam generators: solar-heated steam drives a steam turbine that generates electricity. Trough collectors get good concentration, but the deep curvature of the mirrors is hard to manufacture and can be hard to support structurally.

A second way to deploy the mirrors is called a Fresnel concentrator (see Fig. 19.10). Instead of a single deeply curved mirror, several narrow, flat mirrors concentrate sunlight on the absorber. The term Fresnel comes from the multi-facet lighthouse lens developed by Augustin-Jean Fresnel in the 1800s that became the standard for lighthouses; they are still in use today [25].

Applied to single-axis solar concentration, the Fresnel facets become long mirrors that are nearly flat and easy to manufacture. Prof. David Mills of the University of Sydney developed the compact linear Fresnel reflector (see Fig. 19.11) or CLFR based on an earlier French design of the early 1960s by Giovanni Francia [15].

Fig. 19.11 Compact Fresnel collector

Our company, Focused Sun (Las Cruces, NM, USA) has developed a low-cost linear Fresnel collector. The collector uses four mirrors using "sandwich fabrication", where face sheets held apart by a lightweight core comprise a structure that is low in cost and strong enough to withstand 240 kph (150 mph) winds.

By comparison with flat-plate collectors, concentrating reduces the heat loss from heat absorbing surfaces. Also, enclosing the absorber in a vacuum jacket further prevents heat loss. Concentrating makes a cheaper, more efficient solar module for capturing heat.

Solar energy collection is like fishing. The bigger the net, the more fish are caught. The fisherman makes money if his net is cheap and durable. In solar energy, there must always be some structure that interacts with the small raw energy flux of the sun. We make mirrors with inexpensive sandwich fabrication to reflect and focus solar energy onto a much smaller absorbing surface.

If it were not for the wind, mirrors could be made of tissue paper. A daffodil's petals need not have strong or durable surfaces; they reside in flower gardens protected from the wind. Think cactus. Cactus spends its life in the barren desert where there are no protecting trees to block the wind. Cactus surfaces absorb sunlight but must also be strong and durable to withstand desert winds.

Millions of years of evolutionary forces have made cactus able to absorb sunlight without breaking. Consider the agave cactus, used for making tequila. It has long straight branches up to two meters long that can endure desert winds—gusts are commonly 160 kph (100 mph). These branches have long fibrous outer covers called face sheets surrounding a low-density core. The core holds the face sheets apart and keeps the compression-side face sheet from buckling.

In full production, our mirrors are projected to cost $400 for a 2.2 m^2 aperture collector similar to the one shown above. Each collector captures 1.3 kW under peak conditions. Arid climates like MENA countries can license the collector for local manufacturing. Local labor can be used to manufacture the collector less expensively. Moreover, its raw materials can be purchased much more cheaply on the global market.

19.10 Solar Heat Power Plant

Focused Sun has combined 15 of its linear Fresnel collectors with thermal storage into a solar heat power plant (Fig. 19.12). These collectors fit on the top of a 40′ cargo container that holds a cylinder of concrete storage matched to its expected solar energy capture.

A cutaway of the container shows the cross-section of the system (Fig. 19.13). The cylinder is 1.2-m D and 8-m long and weighs 17,400 kg. It is thermally isolated from the bottom of the container by low-conductivity supports. Around the cylinder, 600 mm of fiberglass insulation prevents the loss of stored solar heat.

Weighing 17,400 kg, the concrete cylinder stores:

Fig. 19.12 Solar heat power plant

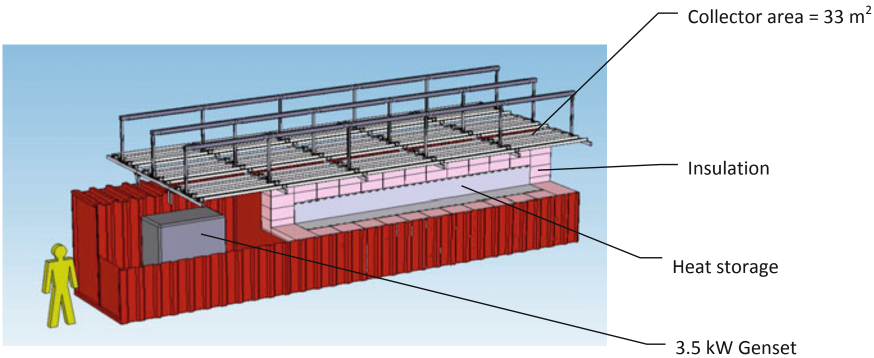

Fig. 19.13 Solar heat power plant cutaway

$$\text{Heat Stored} = 17,400\ \text{kg} \times 0.02\ \text{kW-h/kg} = 362\ \text{kW-h}$$

Hours of heat stored at full power (3.5 kW electric, 16 kW thermal)

362 kW-h/16 kW = 22 h storage

For a 15-collector system with 33 m^2 of aperture, in a MENA climate with a yearly average of 7 kW-h/m^2-day, collects:

$$\text{Heat collected per day} = 33\ \text{m}^2 \times 7\ \text{kW-h/m}^2 \times 70\%\ \text{thermal efficiency} = 161\ \text{kW-h}$$

If the storage delivers that heat to the desal equipment at 70 °C, the time of storage is

$$\text{Hours storage} = 362\ \text{kW-h}/(161\ \text{kW-h/day}) = 2.25\ \text{days}$$

Also in the shipping container is room for auxiliary equipment such as gear pumps, piping, air handlers, and controls. The equipment room can also house a 3.5 kW genset that can provide electrical power for fans and pumps associated with MED desalination.

Called the Microgrid module, it has all the heat and power required to produce about 2 m^3 of clean water a day. Costs are low because labor can be local and raw materials can be priced globally.

19.11 Fresnel Collectors for Desalination

To understand the cost of solar thermal desalination, we will calculate the costs of the thermal module shown above.

Its clean water production is 80 kW-h/m^3 using MED desalination [26]:

$$\text{Cubic meters of water produced per day} = 161\ \text{kW-h}/\left(80\ \text{kW-h/m}^3\right) = 2\ \text{m}^3 = 2000\ \text{L/day}$$

Forecast costs for this small unit are based on \$1000/m^3 for MED desal equipment. In general, such a MED desal unit as small as 2 m^3/day may not be available. However, each of the categories below scale with m^3 of water delivered, e.g., a plant needing 20 m^3 per day would be 10× bigger and cost 10 times as much.

3.5 kW ORC genset to run pumps and fans	\$5000
MED desalination for 2 m^3 per day	\$2000
Concrete heat storage (1.2 m D × 7 m length)	\$5000
Fresnel collectors (15 collectors)	\$7500
Total	\$20,000

Note that the plant is designed to run continuously since the desal equipment is sized for the energy (average sun) rather than peak sun. Thermal desalination equipment consumes 80 kW-h/m^3 per day of clean water. Solar collectors with heat storage must provide this heat.

19.12 Renewable Energy Impact

Fossil fuel consumption and its expansion have contributed to the largest portion of advancement of life. A large part of it would not have happened without the existence of fossil fuels and the possibilities of its uses in power generation, manufacture of new materials, and facilitate the development of daily life in the world. At the same time, however, it has not prevented these uses from causing significant negative impacts on the environment, climate, development, and entire life on Earth.

After centuries of fossil fuel use as the main source of energy, there was a great need to mitigate that damage, forcing researchers to begin their quest for new sources of sustainable energy, which could be compensated first hand. Renewable energy sources can prevent, or at least, reduce the damage left by decades of using fossil fuel.

On the other hand, the great development in modern life, increase in activities and the ease of transportation throughout the earth caused the increase in wastes left by these activities. The related pollution has become a major problem in most countries; it has become a sharp problem in specific countries or regions. One of these countries suffering from waste is Egypt. The problem is getting worse day after day. Consequently, such pollution should be tackled as soon as possible.

In any case, for waste treatment, we will need to do a complete job. The effort will require adequate energy or heat to achieve it, to neutralize its harmful effect, or recycle the waste into new materials that can be reused. The energy we are supposed to use in the process of waste treatment should be renewable energy for several reasons, including:

- Prevent any additional negative impacts that could occur as a result of using more fossil fuels in the generation of energy needed for waste treatment.
- Low, or zero, fuel cost in a renewable energy source contributes to minimizing the cost of waste treatment, making it available to all countries.
- Any waste treatment that produces what can be reused as products or fuels can further contribute to the recovery of the entire primary investment used in the construction of waste treatment plants. This contributes to the further spread of these systems, which greatly improves the cleanliness of the environment and minimizes the harmful effects of waste.
- The appropriate type of renewable energy is supposed to be available locally, which greatly reduces the cost of waste transportation, or it already cannot be transferred from one area to another for a variety of political, economic, logistical or other reasons.

19.13 Conclusions

The expansion of the production of solar thermal power plants and their operation to produce heat or to generate electricity to supply the national grid to treat the waste, or to provide this service to new areas that have not been processed before, is the best way to recover the investments spent for its construction.

On the economics of this type of investment, we found that the total capital needed to build concentrated solar thermal power stations can be paid back in 3–5 years compared to its lifetime which estimated at least 25 years. This also means, that by multiplying capital over five times—apart from having high economic feasibility—it implies the possibility to multiply the thermal/electrical power 5× that we started with, during the life of the plant without new investments.

Our use of these technologies can also be varied to be part of a more comprehensive strategy for the introduction of diverse systems within the umbrella of sustainable development, making them an essential tool for sustainable self-financing, job creation and the development of rural, remote, low-income, and underserved communities. At the same time, we reach our central goal of safe handling of waste and the exploitation of sustainable local resources.

19.14 Recommendations

The most advanced objectives that we are supposed to pursue in adopting specific techniques for the extraction of concentrated solar thermal energy are to provide several basic requirements, including:

1. Expansion of experimental scientific research for the invention of new systems for the generation and storage of thermal energy and improve the design and efficiency of each part of the systems that were invented previously and proved to be useful in their application.
2. Following up on all new materials and techniques that are included in the elements of solar thermal systems, such as heat insulation materials, heat transfer fluids, thermal storage techniques, heat recovery to generate more electricity and so forth.
3. Using grants from government or private capital to be a shareholder and not a donor as is currently prevailing. It is devoted to the development of inventions and known techniques, and to funding prototypes and experimental models of new inventions after the study of their feasibility by experts and specialists. These prototypes if successful can profit from their sale, funding even more development.
4. Create databases and software for all materials and sources of information available in this field.

5. Production of renewable, small, and low-cost processing units that can be purchased in poor and isolated areas for on-site waste treatment and, to the extent possible, avoid large-scale waste collection with its central processing.
6. Localize most of the component alternatives of concentrated solar thermal systems in the countries that need them, primarily Egypt and other MENA countries. All available alternatives should be utilized locally from the materials and elements of this industry, and training of manpower and local cadres in their creation and production.
7. Expansion of the construction and use of such systems in electricity generation, even exceeding the increase in electricity demand, to ensure a large reserve of electrical generating capacity and use them as export to other countries, for water desalination and purification as an important component of national security and to face emergencies in this vital area.

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Chapter 20
Conclusions and Recommendations of "Waste Management in MENA Regions"

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Abstract This chapter is devoted to summarize the conclusions and recommendations of the book "Waste Management in MENA Regions countries". Most of the contents presented in this chapter are extracted from the chapters presented in the book. The chapters include important information on different aspects of waste management for individual countries including Morocco, Tunisia, Egypt, Palestine, Syria, Lebanon, Jordon, and Yemen. A set of chapters are devoted to discussing common aspects of waste management in the MENA regions countries. Graduate students, researchers, policymakers, the decision makers, and stakeholders can benefit very much from this chapter and the different chapters presented in the book.

Keywords Waste · Management · Solid · Landfill · Legalization · Environment · Reduce · Recycle · Reuse · Strategy · Pollution · Sustainable · Integrated · Assessment · Biogas production · Anaerobic digestion · Treatment · Refugees · Thermal · Mechanical · Biological

20.1 Summary

The situation of waste management in the MENA region is different from that in developed countries such as Germany or even in other EU countries. The various factors which play a different role such as poor organizational structure, technical equipment, lack of laws and know-how, and financing have an influence on waste management in many countries in the region.

The existing waste management system is not in a position to ensure nationwide disposal as the main form of solid waste disposal in many developing countries in the

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Middle East, as well as in North Africa, is to discharge it on landfills. Normally in many countries in the region, the solid waste is collected uncontrollably, transported, may be treated and landfilled. This uncontrolled deposition of waste makes high risk for public health and damages the natural resources through the contamination of water, soil, and air.

Although this book demonstrates many new solutions for waste management in several countries in the region, many technical waste treatment processes are being transferred from industrialized countries. Due to the lack of specialist knowledge, the expensive technical processes that do not meet local requirements cannot be used successfully. Therefore, increasing environmental awareness and increasing problem pressure are forcing policymakers to design an orderly waste management system.

Therefore and depends on above points, the weaknesses of the current waste management system in the MENA region can be summarized as follows

- Although there are laws related to the waste management in many countries, it could not be implemented due to the lack of necessary infrastructures and institutions, such as laboratories and treatment facilities.
- There is a lack in the waste management financial system because it is not cover the waste management service in many MENA countries. The waste fees are very low and can cover a maximum not more than 15–20% of the necessary costs for the sustainable waste management.
- The specialized departments in the relevant ministries and offices must take care of the organizational and technical decisions without external support, such as engineering firms meet because such private structures as well as the necessary knowledge and specialized personnel are missing.
- Waste management structures in many cities have no quality management system tools, these necessary qualifications are missing, and there is no good control to evaluate the realized activities.

Therefore and to start developing and improving the above situation of the waste management, many countries in the region must necessarily build up the necessary advisory structures (engineering offices, laboratories, training, capacity building, etc.). This is only possible with the support of decision makers in the responsible ministries. In addition, and for investment and control reasons, there is an international trend toward integration and cooperation with the private sector and involve it in management service.

20.2 Update

It is worth mentioning that in almost all Arab countries there is no separation technology of solid waste materials collection. The lack of solid waste separation is due to many reasons like (inefficient waste management, collection system difficulties, economic and logistical reasons). In turn, these affect the compost qualities. Consequently, these countries need to build a new separation collection system and mix the solid waste with municipal sewage waste to improve C/N and also composting processes.

After the Arab Spring, there was a downturn in of economic growth from about 3.2% of GDP in 2010 to 2.1% in 2011 [1], carrying reduction and/or suspension of investments in MSW collection, recycling, and treatment.

This needs to care about compost quality depends on organic matters in regard to its (physical, chemical, and biological characteristics), which refers to the safe reuse of the product and the impact of the compost on the environment. Compost may contain high concentrations of heavy metals and salts content, etc. These characteristics in the product (compost) have to be very good controlled to protect the environment from pollutions and to avoid detrimental effects on soil organisms, environment and green places. The rest of the solid waste is considered as recyclables like wood, paper, metals, glass and plastics. These are collected from all country parts, waste treatment plants, and countrysides to disposal it in the landfill. However, the landfill is not the optimal method for disposal these components as they have several effects on drinking water quality, human activities, water resources, environment, and public health [2].

Economical and environmental waste reuse/recycle is the best disposal way of waste management. This makes waste management effective and more sustainable by reuse it, energy recovery, and recycle/reuse than conventional it in landfill. Recovery of waste to compost or energy is needed for the agricultural sector which is an important economic factor as in many Arab countries.

Several waste management technologies are available to provide safe reuse and minimization of waste volume with limitation of its risks. The rapid industrialization and increasing the population in many countries in the MENA region generate a huge amount of the waste in form of municipal solid waste, industrial waste, and sewage waste, etc.; this produces very high waste generation in the region (see Fig. 1.1 and Table 1.1).

Currently, and especially after the German standards [3], the disposal of organic solid waste in landfill is not allowed anymore because of its associated risk and also it is not more an economic method to collect gases produces from the landfill in many cases. Therefore, solid waste disposal by the landfill is not more a good solution for the MENA Countries because of the above reasons, and also only less than 8% of the waste is recycled in addition to limited places in many MENA countries which increased by landfill technology with the time. In all cases, landfill is needed for non-organic materials, rest of solid waste treatment like ash produced from thermal solid waste treatment, and an organic rest comes from composting and other solid waste treatment methods which minimize the volume of landfilling place [1].

Nowadays, in the Arab countries and because of the rising environmental awareness, waste management has been given high priority in the political Agenda. Most Arab countries issued regulations, standards, rules, and laws to organize the waste management system in every country. Many stakeholders in national level were involved to improve the waste management and its quality in the Arab countries in the MENA region (see Table 20.1).

During the last decade, good economic growth in the MENA region recovers and develops waste management sectors in the Arab countries, like Iraq which follows the land recovery and reconstruction efforts. While other Arab countries like Saudi Arabia and Egypt have many economic and social reforms in many sectors including the waste management sector. This was done by the support of many international organizations. At the same time, Jordan and Lebanon suffered from hosting a large number of Syrian refugees. At the same time, Yemen, Libya, and Syria were suffering from the war which has a negative effect on all sectors, especially waste management sector. Therefore, the MENA region peace process remains a big challenge and conflict issue in the whole region.

From the cases presented in the book, the solution of the waste management in MENA regions will be by adaption of good quality management (QM) system. The introduction of the QM system analyses needs skills in such a way that the references to the training content and the necessary training facilities can be provided. The modernization and redesign of the waste management system bring changes and new skills requirements for employees.

As an example from out of the region like Singapore which is similar of many countries in the region shows a successful case study and good experience in changing their household waste into clean fuel, to produce electricity and minimizing the rest of waste volume for landfilling. Therefore, waste-to-energy in Singapore shows that waste-to-energy plants covers about 3% of the country's electricity needs from about 37% of incinerable wastes) as shown in Fig. 20.1. In comparison with the USA, the

Table 20.1 MSW stakeholders and their role in MSWM in some Arab countries [4]

Country	Policy and planning	Implementation and operation
Egypt	Central Government	Ministry of State for Environmental Affairs, Ministry of Local Development and Ministry of Finance, NGOs, Governorates and Municipalities
Lebanon	Ministry of Environment, Ministry of Interior and Municipalities, Council for Development and Reconstruction	Council for Development and Reconstruction (CDR), Ministry of Environment (MoE) and Ministry of Interior and Municipalities (MoIM)
Jordan	The Ministry of Municipal and Rural Affairs	The Ministry of Municipal and Rural Affairs, The Ministry of the Environment and Municipalities
Syria	Ministry of Local Administration	Governorates and Municipalities and Ministry of Environment
Tunisia	Ministry of the Environment and Sustainable Development	The National Agency for Waste Management, the Ministry of Interior and Local Development and municipalities
Kuwait	Ministry of Municipal Affairs and Kuwait Environment Public Authority	Kuwait Municipality

recycling rate in Singapore is about 60% while it was only 34% in USA in 2013. The rest is about 53% of solid waste (see Fig. 20.2) disposed of by landfilling and waste-to-energy is about 13% (into electricity), according to the [5].

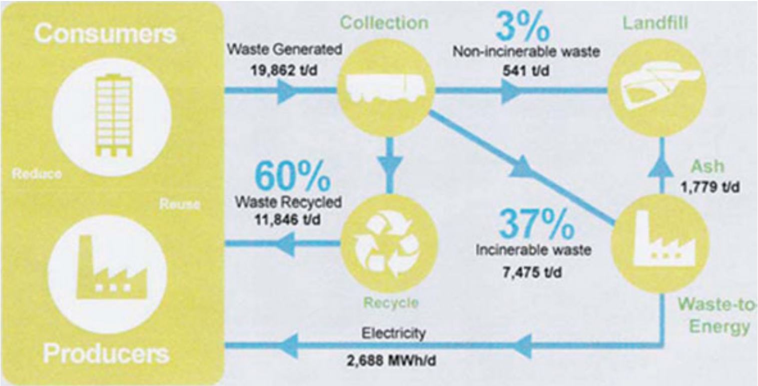

Fig. 20.1 Solid waste management in Singapore as a success story for waste recycling and waste-to-energy experiences in 2012 (Courtesy of Singapore National Environmental Agency). *Source* https://www.thejakartapost.com/news/2013/05/22/waste-energy-singapore-s-experience.html

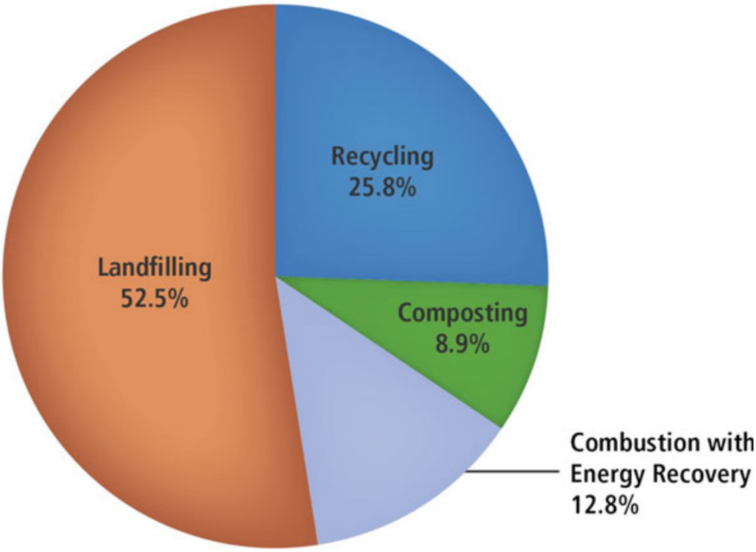

Fig. 20.2 Solid waste management (landfilling, recycling and combustion with energy recovery). *Source* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials, accessed on January 20, 2018

20.3 Conclusions

Under this section, we will present the key conclusions of the presented chapters in this book titled "Waste Management in MENA regions." The chapters in the book are country-based arranged from West to East as follows: Morocco, Tunisia, Egypt, Palestine, Lebanon, Lebanon, Jordon and Yemen followed by the chapters about more than one MENA countries. In this section, we will follow the same arrangement.

20.3.1 Morocco

Morocco has been pushed to adopt an environmental act, adhesion, and ratification of the main international conventions, instauration of administrative and legislative laws made Morocco in front line with the main challenges related to the protection of the environment. Among these challenges, solid waste management represents an important pillar of the national strategy based on the national program of solid waste management. The objectives of the national program include improvement of collection of wastes, built new controlled landfills, restore or close non controlled landfills, improve the treatment and valorization processes, encourage recycling and improvement of the life of solid waste pickers in various landfills. For more details, interested readers are advised to read Chap. 2.

20.3.2 Tunisia

A quick progress has been witnessed during the early 1990s characterized by the establishment of several laws and legislations. Nowadays, this framework has to be revisited and enforced. Institutions were created and their respective roles were clearly defined followed by strategies, national programs, and actions for their implementation at local, national, and regional levels. Significant goals were met while targeting sustainable and integrated waste management during the last decade. Waste management is relatively well organized in the municipal areas despite the existing weaknesses; meanwhile, rural areas are still lagging behind, facing huge environmental problems caused by the release of liquid and solid waste. Since 2011, the situation in both areas has regressed, calling for strong governance and involvement of the private sector with solid support of the civil society; this is the prerequisite to succeed in the decentralization process. Decentralization of decision making represents the main challenge of the upcoming years despite some uncertainty. It is also an opportunity to enhance ownership, to empower local government, and to strengthen the role of communities. For more details, the interested reader is advised to read Chap. 3.

20.3.3 Egypt

In the selection of solid waste landfill, the combination of structural, remote sensing and geophysical data, as an integrative approach, allows the decision makers to draw accurate and detailed images of surface and subsurface geological conditions before deciding the location of the landfill. This integrated approach can be considered as a promising tool to image and evaluate geotechnical and geo-environmental problems related to organic and solid pollutants. The case histories discussed in Chap. 4 indicated that the integration of outcrop and geophysical methods has great importance for the decision makers in geo-environmental assessment and waste management. Continuing applications of this approach and more research into the contaminant geophysical properties should result in further successful applications of geophysical techniques to the characterization of organic waste contaminants and hydrocarbon leakage. Accordingly, it is necessary that fund holders and development managers incorporate this integrative approach into development strategies to avoid many geo-environmental hazards. The present approach introduces recommendations and remedial measures for detection, prediction, and prevailing hazards in urban areas and desert lands. On the other hand, adopting the phytomanagement in Egypt as a sustainable approach for clean environment coupled with meeting future energy demand could help Egypt to optimize the management of solid waste. Moreover, the fact that organic farms are more technically efficient than conventional farms since high technical efficiency is a prerequisite for economic efficiency [6]. This can provide incentives for more farmers to adopt organic practices, which will lead to more production and access to the export market with price premiums. The additional income could help in better management of the agricultural solid waste. However, to promote organic production practices, strategies should intend for information provision, extension services, education and training activities, and providing financial assistance for farmers to adopt organic production.

Since the largest portion of the solid waste is an organic material, the waste recovery is essential to convert the organic waste to biogas. The biogas production from kitchen wastes can help solving many environmental problems particularly the price of the energy is increasing in all over the world and in Egypt as well. For example, anaerobic digestion after some pretreatments can be very effective method in utilizing the organic waste which are easy digestible. Also, the appropriate and environmentally friendly methods for utilizing agricultural wastes and transforming them into valuable resources are very necessary particularly for climate change mitigation and clean environment requirements. The application of the waste recovery methods needs a proper logistics for better management of solid wastes. A major obstacle is that several areas do not receive proper waste collection services with a very low recycling rate, which lead to hazards on public health and on the environment. Therefore, incorporating reverse logistics in waste management activities will have a significant impact on minimizing the disposed waste amount and hence less emissions. In Egypt, the performance of logistics of waste management is not efficient in terms of waste collection, handling, storage, treatment, and disposal with major environmental and public health risks. Interested readers can find more details in chapters from 4 to 9.

20.3.4 Palestine

The critical waste management issues that Palestine is challenged to ever-increasing waste generation and to save landfill space and thus to lengthen the lifetime of the landfill sites. The process of sitting and building of new landfill sites entail, like in other countries, time-consuming processes and require a long time in general, or rather difficult especially in Palestine if considered territorial dispute and political situation. Under such circumstances, it is required to know the actual data for solid waste situation as accurately as possible and to estimate the future waste quantity and quality in order to establish a precise policy on waste management and facility construction plan. Chapter 10 indicated that in 2022, Palestine needs 97 garbage collection vehicles to meet the expected deficit in collection vehicles. The expected waste quantity will reach 2353 tons/day. The total severed population in 2022 is 3139341 (65% of the Palestinian population at that time), and the unit generation rate is 0.75 kg/person/day. This poses a major challenge to the Joint Services Councils for solid waste management (JSC's) in Palestine.

20.3.5 Lebanon

In Lebanon, there are many difficulties to apply a good solid waste management practices some of them are increase in the population, migration of the population from rural to urban areas, no precise studies are made on the right technologies, no legal framework and poor law enforcement, contradiction in policies, no serious actions to implement incentives, no solo administration is dealing with this file, no financial act to recover the cost. Further details are found in Chap. 11.

20.3.6 Syria

Two Chaps. 12 and 13 are presented to show the development in the solid wastes management. In Chap. 12, the feasibility and effectiveness of mechanical, biological treatment of municipal solid waste are compared to the indiscriminate dumping of municipal solid waste to find which one is better concerning the reduction of the methane emission. It concludes that using mechanical and biological treatment can reduce methane emissions about 93% in comparison with random landfilling of solid wastes. On the other hand, the automation process of the thermal sewage sludge disposal together with special solid waste in a stationary fluidized bed furnace of low energy consumptions using (BRAM-Solid waste as fuel to be used as an energy source for sludge thermal disposal and although to disposal the solid waste with sludge at the same time) which was successfully tested by means of a temperature-controlled control. At the same time, wet sludge was used in above test (so there is possibility to save energy needed for sludge drying). The experimental results showed, with respect to the German emission limits, the concentration of SO_2 and NO_x in the flue gas were high whereas that of CO was low. This technology demonstrates the possibility to reduce gases concentration in gas bed to control the gas effluents to meet the German limitation/standards.

The experiment has shown that the NO_x emissions of combustion of high dry residue sewage sludge require regulation. Also, the HCl emissions are too high and require the adjustment of the ratio additive/chlorine.

20.3.7 Jordan

A participatory model to create income generation potentials for the most vulnerable groups in the society (Jordanian Citizen and Syrian Refugees) is proposed based on the findings of studying solid waste characterization and recycling in Syrian refugees hosting communities in Jordan. The current rate of solid waste generation in Irbid and Mafraq is a combined 649,000 tons annually with approximately 85% of this waste is currently being disposed of at landfills or by uncontrolled dumping, while the remaining 15% is recycled and recovered. There is thus a significant scope to increase the level of recycling and recovery for the solid waste in both governorates.

20.3.8 Yemen

The authors of Chap. 16 conclude that a large availability of biomass in Yemen gives a great potential for biofuel production from the biomass resources. Recently, the utilization of biomass from solid to liquid waste at the same time mitigating environmental degradation weakly attracted the attention of the public and private sectors. Joint efforts among relevant stakeholders and actors for efficient waste management to reach international standards while considering the Yemeni context should be of priority. Intensive research and socioeconomic and feasibility studies are required to find alternative solutions for waste management in Yemen.

20.3.9 MENA

Chapter 17 concludes that the main technologies applied for sludge treatment and disposal in MENA countries include thickening, natural drying, and either dumbing or land application for final disposal. It is important to improve technologies for municipal sludge treatment and reuse by adopting an innovative technology to local conditions. It recommends that economic evaluation, environmental and social impacts, climate change, and renewable energy should be considered for sustainable sludge management. On the other hand, Chap. 18 summarize the 3 Rs (reduce, reuse, and recycle) strategies of the agriculture waste in MENA region. The chapter concludes that the reduction strategies consist of improving irrigation efficiency, developing cultivation strategies, minimizing chemical fertilizers, applying control and process monitoring schemes, investing in agricultural sectors, and increasing the environmental awareness and education. The reuse applications compress irrigation, fertilization, bioenergy production, pyrolysis, direct combustion, animal feed, and pollutant adsorption. The recycling approaches include civil construction and composting. The focus on the utilization of agriculture waste is presented in Chap. 19. Most importantly is that the utilization of advantages of agriculture residues (AGR) to substitute forage crops for animal feed which could save millions of hectares of lands that could be devoted for food production for human consumption, consequently a reduction of the imports of wheat and other strategic crops. The author concludes that these agricultural residues, when fully exploited would be expected to foster the development of small-scale agro-industries, create new job opportunities, and provide new arable lands. The expansion of the production of solar thermal power plants and their operation to produce heat or to generate electricity to supply the national grid to treat the waste, or to provide this service to new areas that have not been processed before, is the best way to recover the investments spent for its construction. This chapter focuses on the selection of the best solar energy strategy to be used in wastes management in MENA regions to support greening the environment.

20.3.10 Recommendations

1. More coordination is needed between departments and services at administrative and legislative levels to improve the management in terms of collection, treatment, and valorization. On the other hand, some social action should be engaged towards.
2. Waste management sector is facing several obstacles to be urgently addressed. The low level of collaboration between national institutions and local authorities and prevailing overlapping roles, the low involvement of the civil society, the lack of funding, in addition to the difficulties in adopting/applying new technologies and changing citizens' mindset and attitude are among the main hurdles. It is also important to convey the clear message that waste management does start in the upstream and potential pollution risks incurred by the environment and the population is society's responsibility; the government's role is assigning roles, prioritization of actions, allocation of funds, and regulations setting to guarantee a harmonized framework.

3. Identifying the right indicators and realistic objectives built on reliable figures and data is a must to meet the SDGs connected to liquid and solid waste management for the year 2030. The proper indicators are needed for the different phases of waste management which include identification and classification of source and nature of waste, separation, storage, and collection of waste, waste transportation, treatment (including recovery of resources) from waste, and finally disposal of waste. To achieve good waste management, we need an exploration of all actions and ways to make waste an asset not a burden to the society, the environment, and the country. Also, a strong political will is required targeting the societal benefit. Citizens should play a key role by thinking global and acting local to identify sustainable and economically viable alternatives to liquid and solid waste disposal that could be scaled up. Added to the above, regulations' enforcement and revision of laws in a way that fits with the future societal challenge, the vision of the government. The "polluter pays" principle should be rigorously implemented regardless of the entity either it is an institution or a person.
4. The combination of structural, remote sensing, and geophysical data can be easily used in new urban areas especially those with limited fund, to develop the geo-environmental and geotechnical assessment. Finally, special attention is required to study the geological/structural conditions and to select the suitable geophysical method based on expert' judgment and considering the study area location. This approach could be used to update geohazards assessment in desert urban areas once surface and subsurface data become available to be integrated.
5. Future studies should be conducted to ensure the safety and sustainability of the integrated phytoremediation and bioenergy production systems. Moreover, genetic engineering and biotechnological tools should be used to screen new bioenergy crops that can thrive in the severe environment, capture and accumulate elevated amounts of contaminants, and attain high biomass production and growth rates. The interaction between plant, microbes, soil particles, and heavy metals in the rhizosphere should be completely defined.
6. Policymakers can do a lot to improve efficiency in herbs and spices farming including promoting capacity-building activities to farmers can lead to better production performance, motivating the farmers to upgrade from family farming to commercial farms will help reducing technical inefficiency. On the other hand, motivating farmers to change to organic methods can help to increases in herbs and spices farming efficiency.
7. Future research should also focus on the allocative efficiency in addition to studying the technical efficiency which the first component of the economic efficiency will not only focus on technical efficiency, which is the first component of economic efficiency. The allocative efficiency represents the second component of economic efficiency, and it represents the total factor productivity for each farming system. Both efficiencies are needed to prove competitive of organic farming.
8. Investigating new methods and pretreatments to minimize the problems of utilizing kitchen wastes in biogas production for households and improve the biogas

generation from such valuable wastes, and supporting the decision makers and governments to the households for installing biogas units with low cost. Also, more studies on utilizing agricultural wastes are urgent either for generating new energy resources, for finding new usage or maximizing the recent benefit uses for overcoming the environmental problems.

9. Increasing awareness of the negative impacts of misusing or burring agricultural wastes is required especially these wastes are valuable and potential source of wealth. Moreover, utilizing of local farmer's experience in dealing with agricultural wastes especially in their local sites is very important especially if integrated with the new scientific findings by the specialized researchers. Additionally, supporting governments and policymaking will be very beneficial to the farmer to effective utilizing of agricultural wastes as a wealth source and to mitigate the potential impacts of climate changes. To enable the above targets, it is necessary to make adequate plans and legislation, and it should be taken into consideration to integrate the informal sector with the official waste management sector. A key factor in any new waste management system is raising the people awareness about the benefits of waste separation at source and waste reduction practices.
10. All stockholders should cooperate and work together to provide the required vehicles for the collection, transport and disposal of solid waste to face the future challenges of the waste management specifically in Palestine and generally in MENA regions. Also, data should be published regularly and should be shared to the public particularly, the universities and research institutes.
11. In the absence of a sustainable solid waste management policy, the consequences of the practices will be disastrous for the future of Lebanon. Public authorities must take into consideration the fact that the image of Lebanon is increasingly downgraded and the protection of the environment is no longer the priority for the country.
12. An extensive awareness-raising program on good practices in solid waste management for all citizens is needed. We believe that it is urgent to put in place preventive measures that consist in adopting eco-responsible behaviors and attitudes that make it possible to put in place sorting, selective collection, and recovery of wastes.
13. To obtain the best results for reducing methane emissions resulting from municipal solid waste sector, the process of integrated municipal solid waste management, which includes waste sorting at the place of origin, and processing of the sorting products must be applied on a case-by-case basis.
14. When applying the thermal sewage sludge disposal, the regional characteristics must be taken into consideration. The waste material flows should be prepared, utilized, and disposed of according to the physical and chemical properties.
15. There is a need to establish labor incentive material recovery based on the participatory model to create income generation potentials for the most vulnerable groups in the society, particularly for (Jordanian Citizen and Syrian Refugees) in Syria. In fact, joint efforts among relevant stakeholders and actors for effi-

cient waste management to reach international standards while considering the country context should be of priority.

16. Future trends on municipal sludge treatment and management depend on local conditions and economic evaluation, in addition to the assessment of environmental and social impacts. Climate change policy and renewable energy will also influence sludge management. One of the most interesting topics in selecting sludge treatment and disposal alternatives is the application of cost–benefit analysis, environmental impact assessment, or life cycle assessment.
17. To promote sustainable agricultural waste management in the MENA region based on the 3Rs (reduce, reuse, and recycle), the actions recommended Chap. 18 can be applied. These actions are:

    (a) Identify, develop, and state the national policy and legislation that implement the ideas of agricultural waste management in ways to attain acceptable standards for public health.
    (b) Organize feasible frameworks for addressing waste production minimization, waste collection, segregation, and treatment, materials recovery and reclamation, and conversion of residues to marketable products.
    (c) Stakeholders, operators, and managers should be trained to have sufficient knowledge about the source and composition of agricultural wastes, and then their responsibilities and duties are monitored and regulated.
    (d) Prepare suitable disposal sites that must be licensed and controlled by municipal and regulatory authorities.
    (e) Develop educational programs to enhance public awareness of environmental risk and regulation of agricultural waste disposal.
    (f) Decision makers should participate with public interest teams to sum up the positive and negative impacts of the environmental aspects of the three R's agricultural waste approach.
    (g) Involvement of waste generators, financing agencies, formal and informal organizations, and waste processors to establish sustainable waste management decisions that provide satisfaction to social needs.
    (h) Undertake capacity building to improve agricultural waste management by supporting technology transfer, adaptation, and application.
    (i) Aid for long-term investment in agricultural waste management systems regarding economic, cultural, and social situations.

18. There is a necessity to work out a strategy at both national and regional levels to foster the utilization of (AGR) and to encourage the collaboration of the leading countries for better utilization.
19. Establishment of database and a network for AGR at national and regional levels to compile information on AGR available; quantities, type, seasons and current methods of utilization and disposal, institution involved in research and development (R&D) and those engaged in implementation.
20. Rehabilitate and update existing technologies that suffer from negligence and lack of proper equipment and spare parts, maintenance, etc.

21. Encourage the private sectors and industrial institutions to introduce new technologies of AGR utilization.
22. Enhance the establishment of small industries to absorb entrepreneurs from men and women and increase job opportunities in the region.
23. For an effective waste management system in Egypt and other MENA countries, the following suggestion could be useful to draw a road map for developing an integrated sustainable waste management policy:

    (a) Establishing efficient reverse logistics networks for waste management,
    (b) Greening the waste sector based on the international standards of waste hierarchy,
    (c) Improving the efficiency of collection methods, coordination, and scheduling,
    d) The national strategy should promote the 3Rs; Reduction, Reusing and Recycling,
    (e) Waste management system reformation and engagement of the informal sector within the official system,
    (f) Develop proper capacity plans and vehicle routing plans,
    (g) Raising public awareness about waste reduction and recycling,
    (h) Adopting product lifecycle approaches,
    (i) Adopting technology-based treatment and disposal,
    (j) Imposing legal issues regarding manufacturers' responsibility for packaging and post-consumer waste,
    (k) Collaboration with universities and research institutions to develop better waste management plans.

24. The following measures can protect the environment, helps employment generation and boosting up the economy. Some of these policies include—maximizing recycling and reuse, reducing landfill, ensuring the guidelines are followed by many countries.

    (a) Reform/restructure the organization, carry out the control by introducing the quality management system (QMS) according to the standard DIN EN ISO 9001: 2000.
    (b) Creating awareness among different sectors in many countries in the region and assisting companies related.
    (c) Design of the appropriate waste fee system.
    (d) Construction of the necessary infrastructures such as laboratories, and engineering offices.
    (e) Implementation of adapted technical waste management systems.
    (f) Support for pilot projects and research projects.
    (g) Collaboration with private companies.
    (h) Introducing qualified public relation to promote the public awareness.
    (i) Initial and continuing education.
    (j) Involve facilities in research, planning, private sectors, and waste management processes help to improve waste sector services.

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