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A review on waste management and compost production in the Middle East–North Africa region

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Abstract

Over the last two decades, solid waste management in the Middle East–North Africa (MENA) region has been one of the major challenges due to increasing solid waste quantities and poor waste management practices. With the tremendously increasing amounts of organic waste, MENA countries are under great pressure and are facing the threats of acute air pollution, contamination of water bodies and climate change. As a result, these countries are adopting different methods to cope with this rising challenge of waste management, including composting. This review reports on the different MENA countries' organic waste quantities, disposal methods, organic waste management practices and challenges, along with the potential use and demand of compost, where information is available. The reported data are from 2009 to 2021, with the bulk of the papers being from 2014 and onwards. The total amount of municipal waste collected in the 21 countries ranged from 0.56 million tons in Mauritania to 90 million tons in Egypt, with an average of 16.42 million tons, equivalent to 1.08 kg per capita waste generation per day. Around 55% of this material is biogenous. Many treatments and repurposing methods of this material are adopted in the MENA region, mainly through composting, as it presents one of the most sustainable solutions that lead to immediate climate change mitigation. This article also presents the biotic and abiotic stressors faced by this region, which in turn affect the successful implementation of composting solutions, and proposes some solutions based on different studies conducted.

Keywords

MENA, composting, organic waste, anaerobic digestion, municipal solid waste, biogenous waste, Vision 2030, SDGs

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Introduction

Composting is the natural process of decomposing biogenous material, commonly known as organic material, such as food scraps and green waste, with the aid of aerobic organisms. This process results in the conversion of the biodegradable organic material into stabilised organic substrates and rich soil amendments that can enrich the soil and provide key functions to plants. The composting process takes place due to decomposer macro- and micro-organisms, such as worms, bacteria, protozoa, actinomycetes and fungi that are found in nature. They produce compost as a result of consuming the feedstock for energy. Compost feedstock can come from different waste origins, such as municipal solid waste, urban green areas, farms and so on. The high population growth rates in the Middle East–North Africa (MENA) region have led to an increase in solid waste generation. Negm and Shareef (2020) report that the highest fraction of municipal solid waste generated in Arab countries consists of biogenous materials in proportions ranging from about 35% to 65% in some countries, such as Iraq, Tunisia, Morocco and Yemen. In addition, the growth of urban green areas has increased the amounts of green waste in many parts of the world, consisting mainly of tree wood and bark, bushes, shrub and leaf prunings, and grass clippings originating from municipal parks and domestic gardens (Awasthi et al., 2020; Bustamante et al., 2016). In addition, green waste generated by food-processing activities in agriculture and food industries is significant (Galanakis, 2018). To this end, green waste management is unfortunately considered a significant ecological and economic burden. However, composting green waste constitutes an eco-friendly and economically exciting approach in searching for suitable approaches to solve the disposal problem (Reyes-Torres et al., 2018).

Compost, the final product of composting, can be used as an amendment for soils, a growth substrate for ornamental and/or horticultural plants, and as substrates for microbial inoculants. Thus, it benefits agriculture by providing resources and natural regulatory mechanisms to replace costly inputs that may be

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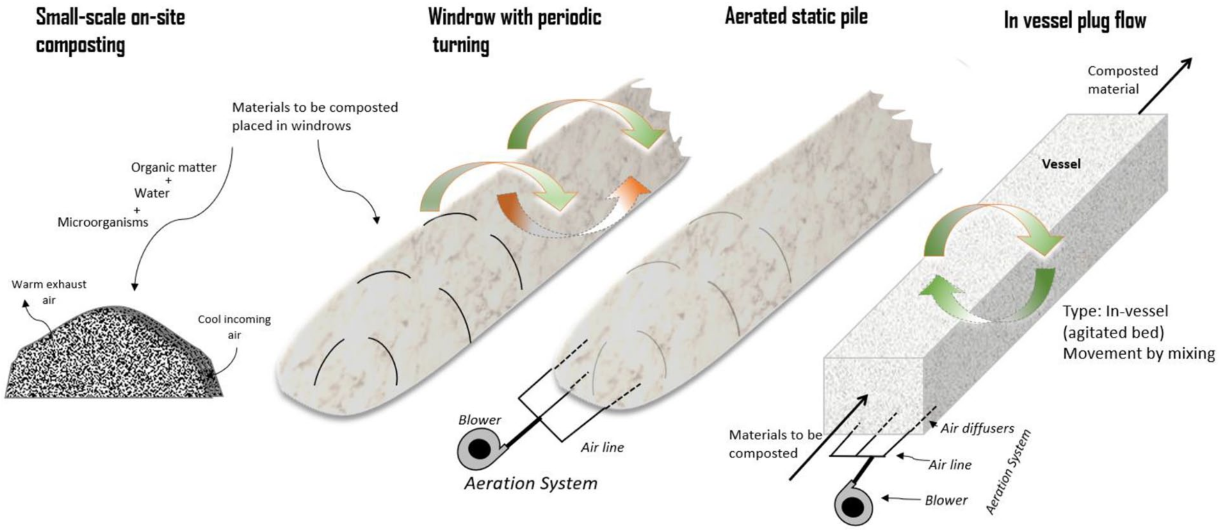

Figure 1. The different most common composting techniques.

harmful to the environment, thereby ensuring long-term agricultural sustainability. By-products generated in this process also include liquid and gaseous emissions (e.g. CO_2, NH_3, CH4) and heat (Ayilara et al., 2020).

The target area for this review article is MENA – a region that has largely been neglected by the science communities, including in global assessments (Awasthi et al., 2020), and one that is characterised by its arid climate in most of its territories (Hammami et al., 2020). With total rainfall less than the quantity required by cultivated crops, water is therefore limited. Moreover, the soil is impoverished in terms of organic matter and unable to hold water for long periods. As such, food production in the region is greatly suffering. Compost may help to combat these two factors in the MENA region and other regions with similar edaphoclimatic characteristics. Amending soils with compost performs a variety of functions, such as, for example, (1) improving the physical properties of the soil, whereby the humus added through compost stabilises the soil structure and improves the soil's ability to retain water, which improves resilience to drought; (2) improving the chemical properties of the soil by increasing the ion exchange capacity of soils which is the basis for the supply of nutrients, both primary and secondary, to plants; (3) increasing the biological activity in the soil, making the soil a living medium, crucial for soil biochemical processes and (4) raising the productive capacity of the soil and improving plant growth (Platt et al., 2014). In addition to promoting plant productivity and soil quality, composting reduces waste volume, eliminates pathogens, deleterious organisms and weed seeds, and sanitise organic wastes. Nowadays, certain enhancements and developments in composting are being made to make the process faster, controllable, versatile, and high yielding in bioeconomy, bioenergy and biofertiliser (Vlachokostas et al., 2021). Depending on certain factors, such as temperature, reactors and aeration rates, various types of composting techniques are available (Cooperband, 2002), such as natural aerated windrow composting, aerated static pile composting, small-scale onsite composting (i.e. composting that can be done at home or small commercial establishments), in-vessel composting and vermicomposting (Texas Disposal Systems, 2020).

Different composting techniques, their advantages and disadvantages

Various composting techniques exist (Figure 1) depending on several factors, such as construction (open/closed) temperature regime, and type and rate of aeration (oxygen supply) (Cooperband, 2002).

Natural aerated windrow composting consists of raw material being mixed and placed into long narrow windrows that are turned (agitated, moistened and remixed) after definite intervals (Ayilara et al., 2020). The process completion duration ranges from 12 to 20 weeks (Table 1). The height of the pile can be about 1.2 m for dense material, such as manure, and can be higher for less dense material, such as leaves, whereas the width ranges from 1.5 to 6 m also depending on the material's density. Feedstocks may be shredded and are frequently turned (mixed) to improve porosity and release the trapped heat, vapours and gases and to remix the hotter and cooler regions of the windrow. Remixing ensures that all materials receive equal exposure to air, temperature and light, thus providing consistent treatment conditions. The temperature of the windrows is also continuously monitored to ensure the optimal timing of turning and speeding up the composting process (Cooperband, 2002). Kitchen wastes, yard trimmings, grease, liquids and animal by-products (such as fish and poultry waste) can be used as raw materials for this process (EPA, 2021b). Ensuring optimal mixture of easy biodegradable fractions and structure-rich fractions is very important for the creation of sufficient gas-filled pores. This method is suitable for large-scale conversions of waste material, such as that produced by large communities. Local governments and high-volume food-processing businesses, such as restaurants, typically use this method for residues from food processing and preparation (Texas Disposal Systems, 2020).

Table 1. Different composting techniques and their comparison (adapted from Texas Disposal Systems, 2020).

Composting method	Pros	Cons
Natural aerated windrow composting	• Takes 12–20 weeks for completion • Medium cost method	• Relatively slow process • Requires larger area
Aerated static pile composting	• Takes 10–13 weeks for completion • Low-cost method	• Requires more monitoring and layering • Requires technical knowledge in constructing set-up
Onsite composting	• Easy to set up • Flexible regarding location and climate	• Takes a long time • Has limited uses • Only for low amounts
In-vessel composting	• Faster composting process • Requires less space • Can decompose almost any type of biogenous waste • Allows to reduce emissions	• Requires very high technical knowledge and proper maintenance • Set-up and apparatus are highly expensive • Favours mineralisation instead of humification • Needs maturation step by natural aerated windrows
Vermicomposting	• Produces high-quality soil amendment • Faster method • Ideal for small spaces	• Needs proper maintenance • Needs large surface area (thin layers) • Worms are extremely sensitive to weather conditions

In *aerated static pile composting*, biogenous materials are placed on top of a perforated surface or pipe, and air is passed either upwards (positive aeration) or sucked downwards (negative aeration) through a blower. Aeration helps to reduce odours, with the rotting material acting as a biofilter. Sufficient oxygen supply keeps conditions strictly aerobic where no anaerobic metabolites are produced, and odorous compounds can be degraded immediately, given optimal conditions. Aeration by sucking has the advantage that waste air can be collected and treated in biofilters, but the disadvantage that 'forced' air flow runs against convective air flow. In theory, this technique may eliminate the need for agitation or turning after a pile is formed. However, standard composting practice requires turning for the outer (cooler) layers of the windrow be brought to the centre of the windrow (hot area) for sanitisation and to achieve homogeneous moisture and oxygen supply. For production of mature compost, this process takes about 10–13 weeks (Table 1). This method works well by homogeneously mixing biogenous waste and municipal solid waste, such as food scraps and paper products. This method is mostly used by landscaping companies, farms and communities (Texas Disposal Systems, 2020).

Small-scale onsite composting is considered the cheapest, easiest and most popular for small-scale composting (cubic-metre scale). In this method, a very small windrow of waste materials, such as food scraps and yard trimmings, is formed on the ground or buried under it and left to decompose by themselves into compost. This method is easy to execute but takes a longer time to create usable compost (up to 2 years if not turned manually; Table 1) and is mostly used by households and small commercial establishments.

In *in-vessel composting*, biogenous material is placed in drums, silos or similar reactors where temperature, aeration and moisture are controlled to provide optimum conditions for decomposition (Table 1). Because it is highly controllable, this process speeds up the decomposition process, specifically the thermophilic phase, and produces mineral-rich but humus-poor compost in a relatively short period (only a few weeks). The apparatus for this method typically has a mechanism for turning the material to optimise aeration and, in turn, accelerate the composting process; however, manual homogenisation through emptying and refilling the reactor can be done if the former is deemed corrosive (Cooperband, 2002). This method can decompose all types of waste materials, including manure, biosolids, meat and more. Due to improved control of the composting conditions, this process is very efficient compared to other techniques. However, the apparatus needed for this method is expensive, so it is mostly used by large food-processing plants and other businesses. This method takes relatively little space and produces few odours (Texas Disposal Systems, 2020).

Vermicomposting uses worms (usually red wiggler worms) to accelerate the decomposition of waste materials, such as food scraps, paper, plants and almost all other organic materials, into a high-quality compost known as castings (Table 1). The compost that this process produces contains high concentrations of nutrients that encourage plant growth. This method is also known as worm farm composting because it is often deployed on a farm scale where worm bins are used to hold worms and compostable material (Cooperband, 2002). This method is often used in schools to teach students recycling. Apartment dwellers and offices can also use this method to reduce solid waste and derive some benefits from composting. It takes about 3–4 months to yield harvestable castings, and the optimum temperature range is between 12°C and 23°C. Higher temperature conditions and direct sunlight can kill the worms.

Methodology

This article is based on the secondary data and findings extracted from scientific research papers and books, literature reviews,

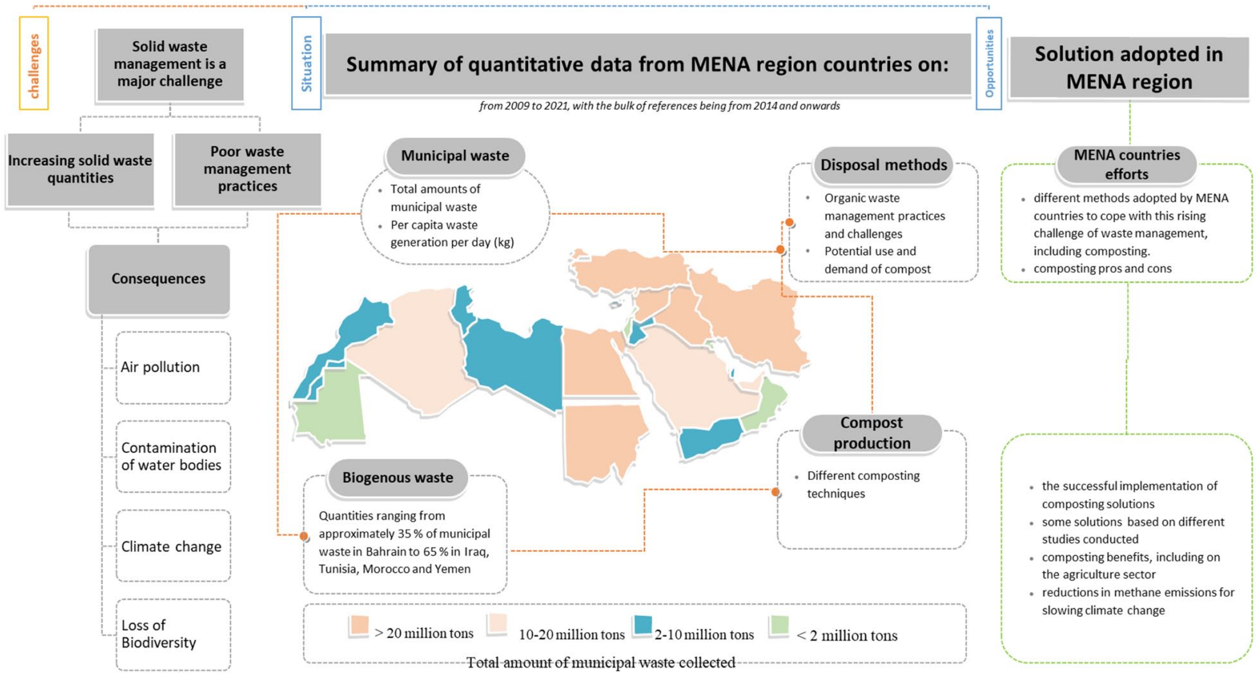

Figure 2. Schematic diagram summarising the literature review on waste management in the MENA region.

governmental reports and open data, and online research on start-ups, initiatives and projects that are addressing waste management in the MENA region. The main focus was to review the amount of generated waste (where available) and waste management practices, adopted by the MENA countries, from collection to disposal, along with its challenges and opportunities (Figure 2). Special emphasis was placed on the treatment and repurposing methods of biogenous material, mainly through composting, as it presents one of, if not, the most sustainable solutions that lead to immediate reductions in methane emissions for the swiftest chance the planet has at slowing climate change. Our selection ranged from 2009 to 2021, with the bulk of the papers being from 2014 and onwards. Major keywords used were the following terms: Waste management in (country name) or (MENA), organic waste treatment OR recycling OR composting, composting in (country name) or (MENA), waste management start-ups OR initiative OR projects in (country name) or (MENA), composting pros and cons, composting benefits, waste per capita in (country name).

Biotic and abiotic challenges to composting in the MENA region and their solutions

The MENA region faces a wide range of challenging biotic and abiotic factors. These environmental stresses include harsh climate, water scarcity, arable land depletion, air pollution, inadequate waste management, loss of biodiversity, emission of methane in open air from various waste sources, less availability of resources, declining marine resources and degradation of coastal ecosystems (Abumoghli and Goncalve, 2016).

The MENA region is the most water-scarce region in the world, with an average renewable internal freshwater resource per capita of 444 cubic metres (calculated for all designated MENA countries,, FAOAQUASTAT, 2018). This is well below the UN water scarcity limit of 1000 cubic metres per person per year (UN-Water, FAO, 2007). Highly variable rainfalls characterise the semi-arid and arid countries. As such, the Gulf Cooperation Council (GCC) countries are highly dependent on non-conventional water resources, such as desalination of seawater, producing 60% of the world's desalinated water. Considering that 86% of MENA's annual freshwater withdrawals are allocated to the agriculture sector (calculated for all designated MENA countries, FAO, AQUASTAT data, 2016), the lack of water available for irrigation poses a serious threat to the region's food security. In fact, only 5% of MENA's land is considered arable (excluding Turkey and Israel) (OECD/FAO, 2018). For example, in Iraq, the ongoing desertification processes are leading to an estimated loss of 250 square kilometres of arable land per year. In Jordan, overgrazing is assumed to have depleted the supportive capacity of rangelands, which cover 80% of the country's total area. In terms of biodiversity, the MENA region offers a diverse set of habitats (from mountain upland plateaus, inland, riverine and coastal plains, sand deserts and wetlands) which host around 5500 endemic plant species, and many wild descendants of essential crops, cereals, pulses, oil- and fibre-yielding plants, vegetables and fruits (Ghazanfar et al., 2019). Research on these species-specific adaptations to their harsh environment, such as drought and soil salinity tolerance, offers very interesting perspectives.

Air pollution is another serious issue in the region where the concentration of particulate matter (PM10) is considered very high, far exceeding World Health Organization (2006) guidelines and even legal standards (20 μg m^{-3} annual mean). This is due to many factors including the intensification of fossil use for low-standard transportation, construction activities and household power generation to accommodate its current growth rate and urbanisation trend and the common practices of open burning of agricultural and/or municipal waste.

Given these environmental stressors, composting can be very challenging in the MENA region. As a result, composting practices have to be adapted to optimise the end product and should be a subject for innovation. It has been proven that the decomposition of various types of solid waste can be boosted, and the quality of compost enhanced using different microbial inoculants and applying zeolites and biochar which provides all the precursors required for natural activities, including interactions with matter and microbial action (Awasthi et al., 2020; Kennedy et al., 2021). These were shown useful for nitrogen conservation, regulating nutrient cycling, remediating pollutants and reducing compaction (Bass et al., 2016; Khan et al., 2016; Waqas et al., 2018b; Wei et al., 2014; Zhang and Sun, 2016). They are also capable of increasing the moisture holding capacity due to their microporous structure thereby optimising aerobic conditions for the decomposing organisms, altering the pH and controlling odours produced during composting. (Chan et al., 2016; Singh and Kalamdhad, 2012; Zhang et al., 2016). In harsh environments of the region, some waste material cannot be decomposed by microbial species and their enzymes typically found in more temperate regions. This warrants the introduction through inoculation of degrading microbial strains or insects with unique physiological mechanisms to aid in such conditions (Ragossnig and Ragossnig, 2021). Depending on the local conditions, this will likely tip the balance of the indigenous microbiome in favour of the newly introduces strains. Furthermore, enzymes such as amylase, protease and keratinase in combination with microbial consortiums can increase the speed and efficiency of composting (Awasthi et al., 2016; Kumar et al., 2013; Villasenor et al., 2011). Some fungal and bacterial species, such as *Bacillus subtilis, Bacillus licheniformis, Macrobrachium rosenbergii, Penaeus monodon*, keratinolytic fungi, such as *Chrysosporium spp., Microsporum spp., Trichophyton spp*., and Myceliophthora and their teleomorphs (*Nannizia spp*., and *Arthroderma spp.*) and some actinomycetes, such as *Streptomyces fradiae*, are capable of spontaneous utilisation of complex compounds (Korniłłowicz-Kowalska, 1997; Kumar et al., 2013). A mixture of these various microbes can be introduced to the composting process to increase the decomposition rate, reduce the waste volume significantly and improve the nutritional and physical qualities of the end product (Chan et al., 2016; Echeverria et al., 2012; Gautam et al., 2010). Another approach is to add inoculants to the compost at the end of the process and to seed the compost with specific organisms for disease resistance, pest control or other quality.

High salinity compost due to excess salt is of major potential problem in the MENA region and poses risks if applied in direct contact with plant roots. In such cases, compost must be mixed with other material, such as sand/soil, to dilute the salt concentrations, but this may change the nature and function of the compost. Although manure, urea and most mineral fertilisers that are commonly used in culture crops also have high salinity levels potentially exceeding that of compost, this is mainly due to nutrients inherently being in the form of salts (Plana, 2020–2021; Rynk, 2021). It is important to remember that the main nutrients in the compost are also in the form of salts, such that high salinity compost should be related to high levels of nutrients (Plana, 2020–2021). Unmixed high salinity compost may be of use in its raw form, such as surface-applied compost for mulch, compost for salt-tolerant and halophytic plants, compost for filter socks and compost for the reclamation of contaminated or mined land, including oil fields (Rynk, 2021).

In a warming planet, the vitalness of sustainable waste management is unequivocal, no matter the challenges. Landfills are a top source of methane emissions, a major contributor to global warming, releasing approximately 12% of the world's total emissions (Hawken, 2017). The biogenous waste (food scraps, yard trimmings, junk wood and wastepaper), which makes up the bulk of most municipal solid waste landfills, undergoes anaerobic degradation, due to the absence of oxygen, and produces biogas or landfill gas (LDF). LDF is composed of a roughly equal blend of carbon dioxide and methane accompanied by a small amount of non-methane organic compounds (EPA, 2021a). This is especially problematic because over the course of a century, methane has 34 times the greenhouse effect of carbon dioxide, trapping heat in the atmosphere over a 100-year period, as per the latest Intergovernmental Panel on Climate Change (IPCC) assessment report (AR5; IPCC, 2019). It also is responsible for nearly a quarter of the world's observed heating over the past two and a half centuries (Warren and Rathi, 2021). With composting, recycling and digesting, these biogenous wastes can be diverted from landfills thereby leading to immediate reductions in methane emissions, which, as per a UN report published in May 2021, is the best swiftest chance the planet has at slowing climate change (UNEP, 2021). Because methane fades away faster, if we stopped emissions today, almost all the methane in the atmospheric blanket would degrade within a lifetime (Warren and Rathi, 2021).

Biogenous waste management and composting in the MENA region

High population growth rates in the MENA region ultimately translate to more solid waste generation. As a result, governments are increasingly seeking the latest waste management technologies for managing waste in a sustainable manner. The highest composition of municipal solid waste generated in Arab countries comprised organic material with percentages ranging from approximately 35% in Bahrain, 45% in Qatar, 50% in the UAE, 55% in Egypt and 65% in Iraq, Tunisia, Morocco and Yemen (Negm and Shareef, 2020). With the tremendous increase in the amounts of biogenous waste produced from green areas (parks, gardens, etc.), households and other sources, countries are under great pressure and are facing the threats of acute air pollution, contamination of water bodies and climate change (Ayilara et al., 2020). As a result, countries are adopting different methods

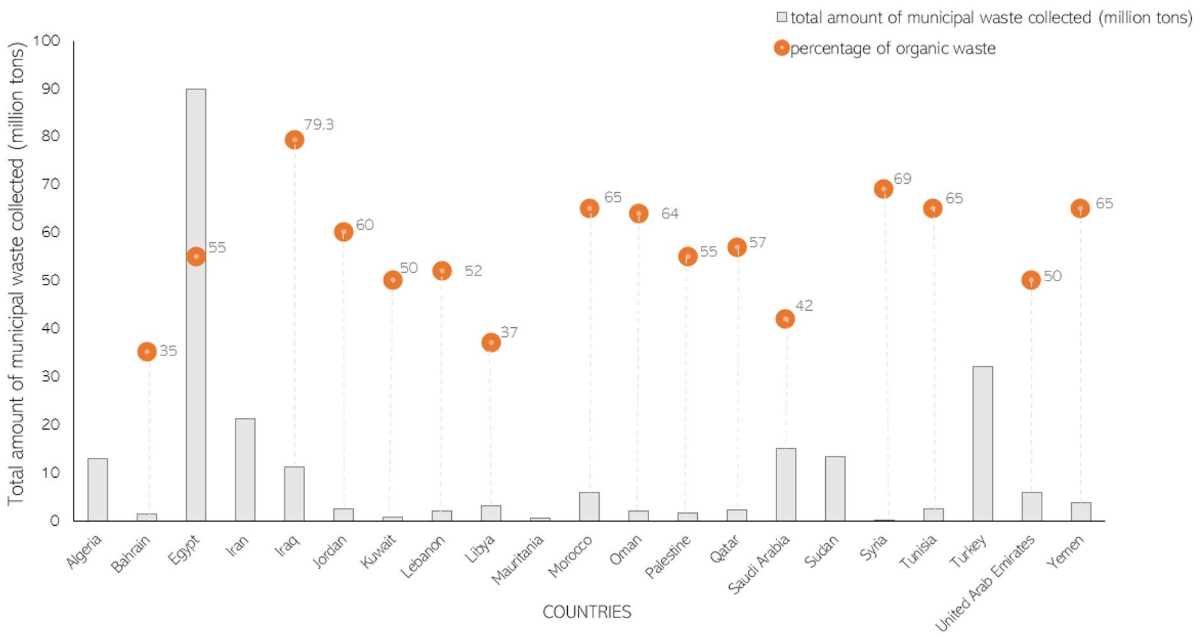

Figure 3. Total amounts of municipal waste generated in different MENA countries and the percentage of biogenous waste; data collected from different sources, as referenced in this section.

to cope with this rising challenge of waste management. Among the recycling and waste management techniques being employed, composting is one that is gaining popularity and is increasingly being adopted for its economic and environmental advantages (Negm and Shareef, 2020).

Over the last two decades, solid waste management in the MENA region has been one of the major challenges due to increasing solid waste quantities (Negm and Shareef, 2020). However, almost all Arab countries have no proper separation technology for solid waste collection, and public awareness of reducing food waste is still lacking. Some studies highlight that food waste increases on religious occasions, such as the holy month of Ramadan, when the preparation of meals largely exceeds families' needs. These findings are supported by the results obtained in various MENA countries, such as Algeria, Egypt, Morocco and Tunisia (El Bilali and Ben Hassen, 2020). In other countries, food waste is also high during social events, such as weddings, births and deaths where 'food is usually prepared on a large scale, in many cases turning into lavish shows flaunting wealth and social status' (Abiad and Meho, 2018).

Composting is one method for biogenous waste disposal that produces a rich by-product that can be used as a soil amendment for agricultural and landscape uses. However, the quality of compost and its impact on the environment depend on the physical, chemical and biological characteristics of the waste material used. If composting is not properly monitored, the compost may contain high amounts of undesirable compounds, such as impurities (plastics, glass, etc.) heavy metals, salts or pathogens (Hogg et al., 2002). Proper control of feedstock materials and processing ensures better protection of the environment and its constituents. Various enhanced materials (e.g. hormones, zeolites, biochar) and techniques are being tested and used for the production of stable compost at a rapid rate (Sun et al., 2016).

In this chapter, a compilation of information on the different biogenous waste quantities (Figure 3, Table 2), disposal methods, organic waste management practices and challenges, and the potential use and demand of compost, where data are available, for the MENA countries is presented.

Algeria

The population growth in Algeria's major cities and urban expansion is directly contributing to the cities' contamination by municipal landfills and the landfill sites located in urban regions. Therefore, a significant amount of investment is required in waste disposal and/or treatment. The country in 2018 produced 13 million tons of domestic waste with the overall daily waste quantity amounting to 0.8 kg per person (calculated from ISWA, 2021). The waste is composed primarily of compostable material, the proportion of which varies seasonally. This is explained by the population's dietary routine and consumption pattern, which is based on seasonal fruits and vegetables and food waste during the month of Ramadan (Derias and Lounis, 2020). As such, composting would be an adequate method of waste treatment. One experiment conducted in Chlef province for a period of 2 years (during different seasons: winter, spring and summer) aimed to determine the optimal conditions and parameters for composting (Naïmaa et al., 2016). The metrics included the type and size grading of the feedstock, the turning frequency, the duration of fermentation and maturation, the temperature, the pH, the content in organic matter and the humidity. It was shown that aerated windrows (trapezoidal shape) with successive turning and eventual water additions were the choice of composting methods. The results indicate that the composts, at the end of the process, had a pH between 7 and 9, relatively high carbon to nitrogen (C/N) ratios that were between 17 and 22, and a Pb rate

Table 2. Total amounts of municipal waste collected per year, per capita waste generation per day (kg), the percentage of biogenous waste and actual compost production (million tons) in different MENA countries.

Country	Total amount of municipal waste collected per year (million tons)	Per capita waste generation per day (kg)	Percentage of organic/ biogenous waste	Actual compost production (million tons)
Algeria	13	0.8	–	–
Bahrain	1.4	1.7	38	0.02
Egypt	90	0.5–1.1	55	20.7
Iran	21.2[a]	0.7	–	–
Iraq	11.3	1.4	79	–
Jordan	2.6	0.9	50–60	–
Kuwait	0.89	1.5	50	–
Lebanon	2.04	1.8	52	–
Libya	3.2	1.1	37	–
Mauritania	0.5	0.5	–	–
Morocco	6.0	0.8	65	–
Oman	2.0	1.2	64	–
Palestine	1.6	0.9	50–55	0.8
Qatar	2.2	2.1	57	0.03
Saudi Arabia	15	1.5–1.8	–	–
Sudan	13.4[a]	0.9	–	–
Syria	0.2	0.65	69	–
Tunisia	2.5	0.2–0.8	65	–
Turkey	32.2	1.2	–	–
United Arab Emirates	6[a]	1.8	55	–
Yemen	3.8	0.6	65	–

MENA: Middle East–North Africa.
The rate of waste reported in the first two columns may not add up due to differences in sources or, more importantly, difference between the waste generated and the waste collected. Data from the period 2012–2020.
–Data not available.
[a]Calculated based on population size and waste generation per capita per day.

that was above the standard but that could be retained by the organic matter in the soil. This implies that it is necessary to establish a more proper sorting at the source to reduce the rates of toxic elements in composts. Nevertheless, the composts did not cause phytotoxicity and contained nutrients that were suitable as fertilisers (Naïmaa et al., 2016).

Bahrain

Bahrain produces waste at 1.7 kg per capita each day (Al-Sadoun, 2018), and the total amount of municipal waste collected in 2020 was 1.4 million tons (Authority, I.A.E. Statistical Abstract, 2021). The Ministry of Works, Municipalities Affairs and Urban Planning also reported that, in 2020, 23,554 tons (or 1.7%) of the waste were recycled, 675 tons (or 0.04%) were composted and 1.25 million tons (or 98.3%) were dump landfilled. During that year, the recycling and composting facilities were not operational full time and saw a dramatic drop from the previous year where the recycling rate was around 20%. No data are reported on the composting percentage in 2019 and the years prior. In terms of waste composition, the ministry reported organic waste (including food waste) amounting to 38% in 2017, followed by 30.1% plastic and 9.7% miscellaneous (Ministry of Works, 2017). One paper studied the feasibility of anaerobic digestion (AD) technology to manage the biodegradable waste in the Kingdom of Bahrain (Abbas, 2020). The results from their cost–benefit analysis suggest that there is economic evidence to recommend AD as a feasible option to manage the biodegradable waste in the Kingdom of Bahrain, but that it will require good segregation at source. It was also stated that AD could help reduce 535,251 tons per year of CO_2-e by diverting biodegradable waste dumping from the landfill.

Egypt

Egypt generates an estimate of 90 million tons of solid waste per year, which amounts to 59,000 tons per day, 55% of which is biogenous (Negm and Shareef, 2020). Municipal solid waste is the most dominant source, with approximately 22 million tons of the total solid waste of which per capita production is about 1.07 kg per capita in urban areas and 0.5 kg per capita in rural areas (2016 estimates; Hashem, 2020). Around 47% of the solid waste is produced from four governorates (Greater Cairo Governorates). Only 12% of household solid waste is recycled, 81% is randomly disposed and the remaining 7% is sent to sanitary landfills (Hashem, 2020). A very big portion of this waste comprises food/kitchen waste that can be used as a major source for compost production. The compost and biogas thus produced depend on the contents present in the kitchen waste. In Egypt, various devices combining composting and AD are being used that decompose biogenous waste at a smaller scale and produce biogas and compost, thereby reducing the amount of waste to a great extent (Sahu et al., 2017). Fertiliser produced through AD is mostly rich in soluble nutrients due to high organic contents in kitchen waste (Li et al., 2016, 2017).

The national production capacity of compost was at around 20.7 million tons per year (Zayani and Riad, 2010), whereas the demand was estimated at 53 million tons per year for the old Nile Valley land and 1.5 million ton per year for reclaimed desert land. This shows a major shortage in the supply of compost compared to the demand (Elfeki and Tkadlec, 2015). Nowadays, Egypt is exercising other uses and utilisations of agricultural wastes, such as use for production of bioplastic and concrete and materials for many products, such as textiles, panel boards, cordage, paper product insulators and upholstery. Other examples are the production of activated carbon from hulls after the biodiesel processing and polymeric composites from the seed cake (Mostafa et al., 2020).

Iran

In Iran, a person generates on average 0.7–1.0 kg of waste per day, of which biogenous waste accounts for a significant amount. Landfilling is the current main method for waste management in its metropolises, and they are not completely sanitary. The composting of biogenous wastes and the use of waste to energy solutions is also common, practised mainly in Tehran, but these have their own limitations (Rupani et al., 2019). For example, there is still a lack of information and experience when it comes to successful industrial composting from co-mingled municipal solid waste (CMSW). One recent study was done in Shiraz City on compost production from CMSW (Azadi et al., 2020). Windrow composting was modified for industrial use to accommodate a daily capacity of 100 tons. The results showed that even though the input waste to the composting site has low homogeneity, the output compost was of 'good' quality, with high fertilising potential and medium heavy-metal content that can be sold without any restrictions. However, the low sale price was due to poor marketing, lack of public awareness and visible impurities, in spite of complying with the required standards. Another study was conducted in Isfahan, on home composting as it is judged to be an effective municipal waste management option (Kopaei et al., 2021). The objectives of the study were to determine the factors that influence the intention to compost at home and to identify the moderating role of composting knowledge in the model. Findings showed that attitude, subjective norms and perceived behaviour control can predict the intention to compost. Moreover, results confirmed the positive effect of awareness of the consequences of composting on ascribed responsibility to compost at home, responsibility on the personal norm and the personal norm on the intention to compost at home.

Iraq

Iraq is estimated to produce 31,000 tons of solid waste every day with per capita waste generation exceeding 1.4 kg per day (Alnajjar, 2019). In Erbil city in Iraq, the composition of the total generated domestic solid is dominated by food (79.3%), followed by plastic (6.3%), paper (5.9%), metals (3.6%), glass (3.4%), and cloth (1.5%) (Aziz et al., 2011). This makes Erbil's municipal solid waste a good candidate for composting due to its waste's high organic and moisture contents. However, to our best knowledge, no composting plant exists there mainly due to private companies encountering various challenges, such as the absence of financial support, low quality of waste due to mismanagement, lack of appropriate technology and proper location (Aziz et al., 2018). However, when it comes to agricultural waste, the production of compost in Iraq has gained importance given the low land productivity partly due to the marginal levels of organic matter in the soil and the depleted plant nutrient reservoirs. This makes it necessary to improve the local soil conditions through the application of compost. Farms generally generate suitable amounts and types of waste for composting, the application of which has been shown to improve soil and crop production. For example, date palm waste is available at Basra and Karbala, wheat straw at Wasit, and reeds and papyrus at Meesan. The compost derived from them has been used to investigate the application rates of compost in the production of tomatoes, cucumber and eggplant grown in plastic houses (Al Taii and Hadwan, 2017).

Jordan

In Jordan, the quantities of solid waste are increasing annually not solely due to population growth but also because of the influx of refugees and industrial, commercial and agricultural expansion. The total municipal solid waste generated by the residential population reached 2.6 million tons in 2015, or 0.9 kg per capita per day, and is anticipated to reach up to 6.0 million tons by 2039 (Aldayyat et al., 2019; Al-Nawaiseh et al., 2021; Yamin, 2019). This municipal solid waste is on average 50–65% organic. However, composting has never been practised on a full scale as part of the solid waste management system, and 90% still ends up in unsanitary landfills and dumping sites. This is partly driven by the absence of incentives for market and quality standards in municipal solid waste composting. A recent assessment of the sustainability of Jordan's solid waste management sector using the Sustainability Window tool showed that the sector trends were unsustainable (Hajar et al., 2020). As a result, the National Green Growth Plan in general and the National Solid Waste Management Strategy in particular, launched by the Government of Jordan with the aim of facilitating the transition to green growth, set the Jordan Vision 2025 with a 33% reduction target in the solid waste amounts disposed in unsanitary landfills or dumpsites. To this end, the strategy recommends five major composting facilities be put into operation starting in 2025 (Abu Qdais et al., 2019).

On a small scale, composting is mainly done for farming and agricultural applications. There are also a few plants producing organic fertilisers from animal manure using modest composting methods. However, most local farmers apply fresh manure and other biogenous wastes as natural organic fertiliser without any pre-treatment. Even though farmers expressed strong interest in

Table 3. Municipal composting plants in Lebanon (GIZ, 2014a).

Composting plant	Capacity (t d^{-1})	Technology
Coral	300	Windrows
Saida	300	Anaerobic digestion
Ain Baal	150	Aerated agitated bed
Bint Jbeil	20	Aerated floor
Kherbet Selm	15	Drums
Aytaroun	15	Windrows
Ansar	10	Windrows
Khiyam	10	Windrows
Ain Ebel	10	Windrows
Qabrikha	10	Windrows

composting, especially to handle their own wastes, such as manure and field residue rather than purchasing compost, the application rate is still low or non-existent. This is due to the lack of experience and knowledge and the fact that purchasing compost is more expensive than raw manure (Kippert et al., 2020).

Kuwait

Kuwait produces waste at an average of 1.5 kg per capita per day (Al-Sadoun, 2018). Currently, Kuwait has no waste treatment facilities other than limited recycling, making landfilling the only way to handle waste. According to the Kuwait Central Statistical Bureau (2018), the total municipal solid waste landfilled was reported to be 893,044 tons in 2018 compared to 426,498 tons in 2000. It comprises 50% food waste according to three studies conducted during different periods (Al-Jarallah and Aleisa, 2014; Hamoda, 2016; Koushki and Al-Khaleefi, 1998). Because landfilling is the only waste management system in Kuwait, the non-valorised disposed waste is considered a huge loss of resources. Recently, due to its environmental friendliness, easy implementation and reasonable investments, composting has been given significant attention. High-quality compost application would be an efficient strategy to improve the quality and fertility of Kuwait's sandy soils and may boost agricultural opportunities (Albeeshi et al., 2020).

Lebanon

Lebanon generates approximately 2.04 million tons of municipal solid waste every year or 1.05 kg per capita per day (Romboli et al., 2018). A big portion of this waste is biogenous, approximately 52% (Massoud and Merhebi, 2016; MoE, EU, and UNDP, 2014). Various techniques for solid waste management are implemented in different parts of Lebanon where unmonitored and unsanitary dumping of waste on seashores and hillsides is still a common practice. There are various efforts in motion to change this trend and to develop solid waste management systems for most of the areas of Lebanon, particularly in urban areas. These efforts focus on constructing controlled sanitary landfills and the facilities of sorting, recycling and composting or waste-to-energy systems. Due to the high organic content of municipal solid waste, some municipalities have or plan to set up community or municipal composting plants. Table 3 lists the municipal composting facilities in Lebanon with the technology in place and their capacities in tons per day.

The Coral composting plant uses the windrows system (12 windrows, 4–5 m wide and 2.5–3 m high), a trommel screen and a densimetric table for polishing with a composting cycle between 65 and 70 days. The produced compost is given for free to institutions and individuals. Nonetheless, only about 13% of incoming waste is processed in the Coral composting facility, and the remainder is baled, wrapped and hauled for final disposal at the Naameh Landfill (currently at Costa Brava). The Coral composting plant has its operational problems: bad odours, limited space, closeness to residential areas and mechanical failures. The leachate produced at the plant is then treated by anaerobic and aerobic processes. The effluents from this primary treatment are then combined with the biofilter discharge water and sent by tanker trucks to the Ghadir wastewater treatment plant south of Beirut (Abbas et al., 2017). With the financial support from the European Union, a sorting and composting facility was built by the Office of the Minister of State for Administrative Reform (OMSAR) near the dumpsite area in Tripoli, Lebanon's second capital, with a capacity of 420 tons per day. However, its operation was halted after various complaints by citizens about its foul odour emission, weak recycle percentage (less than 5%) and bad quality of compost produced (Halwani et al., 2020). Various start-ups are emerging in Lebanon to solve the biogenous waste management problems and composting challenges. Compost Baladi is one of these start-ups that started working in 2015 to deliver onsite composting solutions for business and gated institutions. Their start-up includes earth cubes, container composters and some other customised set-ups (Compost Baladi, 2021). Another start-up is BIOwayste which makes use of a machine and bacteria additives to convert biogenous waste material into cooking gas and liquid fertiliser through anaerobic treatment (BIOWAYSTE, 2021).

In August 2020, USAID/Lebanon assigned ECODIT – an international development group with operations in the water, energy, environment and urban and local governance sectors – the Diverting Waste by Encouraging Reuse and Recycling (DAWERR) activity to establish sustainable and replicable integrated solid waste diversion and valorisation solutions in rural areas of Lebanon (ECODIT, 2020). It aims to develop sustainable composting value chains for biogenous waste, strengthen existing recycling value chains for inert recyclable material, support replication by municipalities across Lebanon, implement integrated solid waste management solutions for clusters of municipalities and increase economic horizons for the people of Lebanon (ECODIT, 2020). It adopts a closed composting system that uses containers and biofilters to filter gases and odours, to speed up the composting process and to ensure high-quality compost using relatively smaller areas.

Compost products in Lebanon still suffer from a bad reputation where authorities claim that there is no potential use for them, and farmers are suspicious about using a waste-derived product. Nonetheless, agricultural demand for compost exists in Lebanon, with a current consumptions estimated at 10,000 tons per year (Azzi, 2017). The prices range between US$200 and US$700 per ton when packaged in small bags. Other occasional applications are for quarries rehabilitation or as an alternative landfill cover, which can accept lower quality compost. As for the potential for compost production from municipal solid waste nationwide, it is estimated at around 600,000 tons per year (1,600 tons per day). Considering the agricultural land use, this equals 2.4 tons per year per ha (i.e. applying a layer of 0.5 mm per year; Azzi, 2017).

Libya

The amount of municipal solid waste generated in Libya is estimated at 3.2 million tons per year, or 1.1 kg per capita per day (Hamad et al., 2014), where 97% of the waste is dumped in uncontrolled open areas (Ali, 2013; Sawalem et al., 2009). For example, in Benghazi city, an average of 1.1 kg per capita per day of waste is dumped to landfill, out of which 37% is food waste, followed by plastic 31%, paper 14.7%, glass 7.2% and metal 6.3% (Baba et al., 2018).

In 2019, an evaluation was done to find out the most appropriate solid waste treatment in Libya (Badi et al., 2019). The selected criteria were based on environmental, sociocultural, technical aspects and economic aspects. The result showed that AD ranks highest in the classification in Libya, and compost ranks higher than landfilling and incineration.

Mauritania

In Mauritania, the quantity of municipal waste generated was estimated in 2014 as 540,000 tons, of which 0.5 kg per capita per day is generated in urban areas and 0.3 kg per capita per day in rural area (GIZ, 2014c). It is estimated that 37% of municipal solid waste are landfilled while, 55% are openly dumped and 8% are recycled (GIZ, 2014c). The private sector is involved in waste collection in the capital city Nouakchott through an international operator (Pizzorno) which focuses primarily on recovery and recycling of waste (plastic, scrap, etc.), whereas the municipalities govern waste management in the secondary cities of the country, but are ill equipped in technical, human or financial capacity. As of 2014, a sustainable national development strategy was being elaborated since 2006 to, among other objectives, strengthen the institutional and political means for efficient management of the environment and natural resources in an integrated and participatory approach and in accordance with international conventions (GIZ, 2014c). It is unclear what the current status of this national strategy is.

Morocco

Morocco generates massive amounts of solid waste amounting to approximately 6 million tons every year or 0.76 kg per citizen per day in urban areas, and 1.47 million tons or 0.28 kg per capita per day in rural areas (Maaouane et al., 2021). The waste generation is increasing at an approximate rate of 3% per year (The World Bank, 2013). It is estimated that 65% of the waste is biogenous (Negm and Shareef, 2020). The country faces severe environmental degradation due to the improper waste management and lack of proper infrastructure for disposing biogenous waste. A survey shows that before 2008, only 70% of solid waste was being collected and only 10% of this collected waste was being disposed of in an environmentally friendly manner. There were 300 unmonitored dumpsites and about 3500 waste pickers (including 10% children), who were living at these dumpsites (Hansen, 2020). The waste collected is mostly burnt to reduce its volume. This poses a lot of risk to Morocco's population through air pollution and the greenhouse effect (The World Bank, 2013). In the region of Souss-Massa (delineated by the High-Atlas Mountains in the north and the Anti-Atlas Mountains in the southeast) alone, huge quantities of organic horticultural wastes are generated, estimated at about 1,307,465 tons per year. It is estimated that 13 million euro worth of N, P and K fertilisers can be generated by composting all horticultural wastes (Azim et al., 2017). In recent years, a Moroccan company, BIODOME, has been very active in the production of specialised composting devices, also known as Biodome. These specialised devices can produce digestate (which can be used as fertiliser) and biogas from waste at a rapid rate and a smaller scale without producing any noise or smell (The Next Society, 2018). Regarding composting in the country, a recent study designed a model to estimate the potential demand for compost from farmers in the Rabat area based on the available arable agriculture land (Maaouane et al., 2021). The study showed a considerable fluctuation of demand over the planting seasons, which would necessitate a storing area for unsold compost – a barrier to adoption. Yet, despite this high demand for compost and the abundant availability of the feedstock, Morocco appears to struggle with operating successful and efficient composting plants. According to Azim et al. (2017), who undertook an assessment of the existing composting plants in the region of Souss-Massa, the majority of the composting plants in the region were operating bad practices which included close proximity of mature piles to raw materials, permeable composting surfaces, incomplete/immature compost production.

Oman

In Oman, the total quantity of municipal solid waste stood at 2.0 million tons per year (Umar, 2020). The nation produces waste at 1.2 kg per capita per day and targets a recycling rate of 80% by 2030 (Al-Sadoun, 2018). The composition analysis reveals that the largest fraction of the municipal solid waste stream (64%) is biogenous waste (food waste, garden waste and paper waste; Palanivel and Hameed, 2018). All the waste generated is being dumped in more than 300 dumpsites located in different parts of the country. Some studies in Oman explored the energy production potential from high-biomass waste (Umar, 2018). In addition, an action plan for solid waste management in Oman was promoted in an Eco-composting campaign (Be'ah (Oman Environmental Service Holding Company S.A.O.C), 2016; JICA, 2012). The compost produced from the biogenous waste could be utilised to enhance agriculture activities and for amending these sandy desert soils (Umar, 2020).

Palestine

Palestinians from the West Bank and Gaza generated about 1.6 million tons or nearly 4,356 tons per day in 2018. Average production per capita is about 0.9 kg per day (Thöni and Matar, 2019). Biogenous waste makes up 50–55% of the total waste generated. The remaining 45–50% portion of the waste comprised glass, plastics, metals and cardboards. Approximately, 82% of the waste generated ends up in sanitary landfills, whereas 17% is sent to the open dumpsites and only 1% is being recycled (Yaqob, 2020). Disposal methods are mainly landfilling and dumping (random or controlled). It is estimated that 30–35% of municipal waste is illegally dumped, and 65–70% is disposed in one of the six operational landfills existing in Palestine. There are currently 12 operational Palestinian Treatment Centres (11 in West Bank; 1 in Gaza Strip) and 3 newly constructed ones. These have a good potential for waste segregation and recycling activities, thus helping to reduce the amount of waste finally disposed in landfills; however, their use is still underdeveloped (Thöni and Matar, 2019). Recently, the government of Palestine signed a contract with DECOST consortium to bring out a new composting system in Palestine. This system will be based on community composters adapted to this region's social and climatic reality (ENI CBC Med, 2021). Composting municipal and agriculture waste in the Gaza Strip will produce around 800,000 tons of compost per year, and the agriculture demand stands at 160,000 tons per year (20%) (Nassar, 2015). The main barriers to market development for organic waste-derived compost in Gaza are the deficit of high-quality compost and limited information on compost usage and its benefits.

Qatar

Qatar generates approximately 2.2 million tons of municipal solid waste each year, corresponding to a daily generation rate per capita of about 2.1 kg. A major portion of this waste comprises biogenous material (approximately 57%), while the rest consists of glass, plastics and other materials (Qatar Development Bank, 2017). The Qatari government has been making significant moves in recent years to increase the waste recycling rate and reduce domestic solid waste. Production of biochar and compost from biogenous waste are the important issues being addressed by these moves (Rehrah et al., 2018). In 2011, Domestic Solid Waste Management Center (DSWMC) started working in Qatar and is considered the first integrated solid waste management facility in the Middle East. This facility can produce energy from waste using advanced technologies for separation and mechanical recycling and composting. Reports show that, in 2018, DSWMC was recycling manure and producing compost for agriculture at the approximate rate of 100 tons per day (Mathew, 2018). Within this framework, the Ministry of Municipality and Environment identified key compost-related issues, including the absence of best practices for compost processing and the absence of segregated biogenous waste collection programmes, and in response, had put strategies in motion for the duration of 2018–2023, which included the establishment of a waste treatment facility to produce compost from waste material using windrow composting technology and to unleash campaigns to encourage change in people's behaviour regarding waste management (Mathew, 2018).

Saudi Arabia

Similar to its neighbouring country, the Kingdom of Saudi Arabia (KSA) has one of the highest rates of food waste in the world (Baig et al., 2019). With population of around 35 million, Saudi Arabia generates more than 15 million tons of solid waste per year. The per capita waste generation is estimated at 1.5–1.8 kg per capita per day (Zafar, 2021). Some of its major challenges regarding food waste management are solid waste segregation, inadequate legislation, well approved traditional dump disposal practices, public attitudes, and lack of awareness (Mu'azu et al., 2019). Following the announcement of Vision 2030, KSA established the National Center of Waste Management, which is now responsible for sustainable waste management. This aims to divert 82% of the total waste from landfills, raise recycling up by 42%, establish 1329 facilities to manage 106 million tons of waste, create 77,000 jobs and contribute SR120 million to the country's gross domestic product by 2035 (MWAN, 2021). Nowadays, there are various facilities working in Saudi Arabia to produce compost. However, the quality does not comply with international standards. It has been reported that the produced compost is plagued with bad odour, low nutrient content, excess heavy metals and high pH, making it not of much use for improving quality and fertility of soil (Alzaydi et al., 2013; Zajonc et al., 2014). Optimising compost production using natural zeolites and biochar (mineral supplement and sorption/chelation property; Awasthi et al., 2020) could benefit the KSA's economy with a total net savings of about US$70.72 million per year (Waqas et al., 2018b). In their study on continuous thermophilic composting (CTC), Waqas et al. argue that 'CTC can be implemented as a novel method for rapid decomposition of food waste into a stable organic fertilizer in the given hot climatic conditions of KSA and other Gulf countries . . .' (Waqas et al., 2018a).

A start-up, Edama, was launched in 2017, to produce organic waste recycling solutions designed specifically for desert climate conditions and desert agriculture needs. It builds and operates customised composting facilities for communities. These facilities convert biogenous waste into soil improver products which can then be sold to local farmers, home gardeners and landscapers. They adopt a Turned Aerated Piles (TAP) system for cost-effective composting, working at small scale. The TAP system contains biofilters for odour control and other technologies for the production of high-quality compost in a controlled way and produces stable, high-quality compost in a shorter period (7–8 weeks). Edama's main products include Edama Desert Compost to increase fertility of sandy soils and Edama Palm Peat to support healthy plant growth. In one greenhouse trial, Edama tested the compost's growth promoting effects and concluded that Edama Desert Compost yielded five times more plant biomass than the control and outperformed manure (Edama, 2021).

Sudan

Sudan generates waste at a rate of approximately 0.9 kg per capita per day (Awad et al., 2017). Despite the depleted levels of organic matter (<1%) and nitrogen content in Sudan's soil and the high cost of inorganic fertilisers, the use of organic fertilisers in Sudan is still very low. This can be attributed partially to the lack of information on the composting techniques and lack of understanding of the value of organic fertilisers in the maintenance of soil fertility (Sulieman et al., 2009). One of the main sources of agricultural wastes in Sudan is the date palm trees, which give about 3.5 million ton of dry leaves annually (Dawi, 2014). Some farmers traditionally haphazardly produce poor quality composts from crop residues, livestock wastes and other farm by-products. This is generally done without regulations, quality control measures or any legal supervision. Nevertheless, over the past few years, there have been developments in mass production of compost, such as in large-scale modern factories, primarily in Khartoum State. Many enterprises are selling bulk compost, compost tea or processed animal manure, targeting local consumption. Mixtures vary from sheep, chicken and cattle manures to chicken and cattle manures with agricultural residues (Elnasikh and Satti, 2017).

Syria

In Syria, the management of municipal solid waste is a serious challenge facing both national and local authorities due to the destruction of infrastructure, damaging or looting of collection vehicles and waste containers, devastation of government institutions, displacement of residents into safe areas as a consequence of the 2011 conflict (Noufal et al., 2020). According to Saghir (2021), current solid waste management practices include the following:

- Disposal to a dumping site especially in communities in North Syria that are not served by governmental solid waste collection after the 2011 uprising;
- Solid waste left in public areas, such as streets, where people are under the poverty line and local councils do not have the capacity or resources to transfer the solid waste to the dump sites, most notably in Aleppo, Homs, Hama and in neighbourhoods of Damascus;
- Free public solid waste collection where each local council in each community handles the solid waste collection and disposal without charging any fees. These local councils are mostly supported by Non-Governmental Organisations (NGOs);
- Paid private garbage collection where there is absence of support which forces the local council of each community to charge for solid waste management activities;
- Garbage buried or burned; mainly due to the Syrian crisis where people and the local councils do not have enough resources for conducting solid waste management.

There is a lack of accurate data on the quantities of the waste generated, their types and characteristics or even the waste disposal needs of the populations. Interviews by Noufal et al. (2020) were conducted with the staff of the municipal waste management department in Homs, who reported that, in 2018, an average of 600 tons of municipal solid waste was generated per day and an average daily amount of 0.65 kg per person, out of which 69.1% was composed of biogenous waste. Nevertheless, despite the high percentage of biodegradable organics, composting has never been considered as an option for solid waste management in Homs. A technical assessment was administered to understand how to convert solid waste into compost in households in North Syria, non-state armed group (NSAG) controlled areas (Saghir, 2021). The results indicate favourable weather conditions for composting with 99 to 111 days of temperatures ranging between 10°C and 35°C and a potential reduction of the volume of solid waste per household with composting by 45–50%, which lowers risk of environmental pollution and cost to manage the generated waste management. Potentially, each family could produce 0.7–0.8 kg of compost per day or 0.08–0.13 kg per capita per day. Moreover, 94% of respondents to the questionnaire in Aleppo and Idlib governorates have access to the farmland and out of them, 75% use fertilisation. However, 92% expressed their lack of knowledge of the composting process, with 57% interested in acquiring this knowledge. Reasons for disinterest were 13% do not have composting tools, 67% are not familiar with composting, 13% do not need compost and 6.7% are averse to the time required to perform the composting (Saghir, 2021). Raising awareness for promoting large-scale composting in the country will divert a significant fraction (>60%) of municipal solid waste from the landfills, will supplement the use of fertilisers in the agricultural sector and will reduce the expenditure on importing these fertilisers (Noufal et al., 2020).

Tunisia

Tunisia produces about 2.5 million tons of waste each year of which roughly 65% is biogenous (Negm and Shareef, 2020; UNEP, 2020). Urban dwellers generate on average 0.8 kg of municipal solid waste per capita per day, whereas rural dwellers generate only 0.2 kg (Abdulrahman, 2021). To manage this problem, the National Strategy for Sustainable Waste Management was launched in Tunisia in 1993. This initiative aimed at the valorisation and recycling of biogenous wastes, including domestic, green and biosolids by composting. In fact, composting for agricultural use is a worthwhile option driven by the high demand for organic matter used as soil fertiliser.

One of the important steps taken by the government with regard to composting and waste management is the launch of a platform for organic waste composting in Djerba Island and the creation of selected waste disposal sites in some specific areas. Production of compost at this platform is considered as an important objective of this initiative (Negm and Shareef, 2020). The first plant commenced operations in 2012 and disposed waste collected from eight hotels and other green waste from the region. This plant had a forced aeration composting system for controlled aeration, shredder for shredding waste material to small pieces and a biofilter to control odour emission and generation (Ben Abdallah, 2013).

Turkey

According to the recent statistics, the amount of municipal waste generated in Turkey in 2018 was nearly 32.2 million tons with a daily per capita average of 1.2 kg (Kanat and Erguven, 2020). With this tremendous amount of waste, Turkey has been able to achieve 77% collection coverage rate, whereas its unsound waste disposal rate is at 69%. The waste sector emissions were calculated at 17.2 Mt CO_2 eq. in 2019, which is a 56% increase compared to 1990 but a 5% decrease compared to previous year (Turkstat, 2021). Some other studies also show that between 2001 and 2010, Turkey did not recycle any of its municipal solid waste (Bakas and Leonidas, 2015). However, in recent years, Turkey has taken some initiatives for waste management and compost production. To increase compost production, Turkey launched the Turkey Composts! Project. This project was aimed at biowaste management and increasing awareness of compost among the public. Nevertheless, there has not been any prominent progress in the field of composting in Turkey, and it is still not up to the mark for waste management (ACRplus, 2017).

In 2007, the Turkish government initiated a plan to spread awareness that uncontrolled and improper disposal of waste, which has become a common habit in most of the people, poses a severe threat to the environment and a great risk to the 70 million inhabitants of that time. As a part of this initiative, the number of monitored sanitary landfill sites for burying wastes was increased from 90 in the 1990s to roughly 3000 (Deutsche Welle, 2015).

United Arab Emirates

The United Arab Emirates (UAE) ranks among the top nations of the world in per capita waste generation with estimates of about 1.76 kg per capita per day (El Bilali and Ben Hassen, 2020). Roughly, 38% of the food prepared is wasted everyday which increases to 60% during Ramadan. Moreover, 40% of average household bins in UAE comprise of food scraps and 55% of biogenous origins (Dubai Carbon, 2020; Negm and Shareef, 2020). Due to increasing population density and economic activities, solid waste is rising at a rapid rate, where most of the waste ends up in municipal landfills or dumpsites, releasing a great amount of greenhouse gases and imposing great danger to the environment, such as the case with the Emirate of Ajman (Al Dabbagh, 2021). The UAE government has initiated various programmes to ensure a safe, healthy and sustainable future for the UAE. As a part of these efforts, the government established Dulsco – an environmental organisation and the official waste management partner for Expo 2020. Biogenous material, which is estimated to make up 48% of the event's waste, will be turned into fertiliser and biofuel for use on site through a 16–20-hour-cycle digester (Hammond, 2019). No further mention on the mechanics of this digester is found. However, in 2012, Dulsco launched Converta, which combines engineering with biosciences, to transform biogenous waste into solid usable digestate in 2–3 days, which can then be used as soil enhancers for agricultural and landscaping purposes (Construction Week, 2012). Converta contains two major chambers that systematically treat biogenous waste by adding natural plant extracts at regular intervals, using low amounts of electricity. A biostimulant that is added using an automated dosing system, automated temperature, controlled movement and oxygenation stimulation contributes to the rapid conversion of the waste.

Abu Dhabi Waste Management Centre (Tadweer) has launched in November 2020, a new biowaste digesting unit as part of Abu Dhabi Environmental Vision 2030. This unit can decompose all types of biogenous waste into a highly compact fertiliser within 24 hours. Biogenous waste is fed to the unit which uses a shredder to shred it into small pieces. Then, a special enzyme is introduced to this shredded material which decomposes it into digestate. The machine used in this process can control conditions, such as moisture, aeration and temperature. This process reduces the volume of the waste by 80–90% (Khaleej Times, 2021).

In Dubai, Tadweer Waste Management LLC's composting facility utilises a European technology of composting. This technology consists of an oxygen-controlled composting blowing system that also ensures a sufficient moisture content and optimum C/N ratio (Table 4). All these factors speed up the decay of organic materials and heat up to 75°C to eliminate weed seeds, pests and pathogens. Treating with oxygen also optimises the nutrients that plants need.

Other prominent composting facilities in the UAE include the following:

- CULTIVA facility in Al Ain city
- The Bee'ah Waste Management Centre compost plant in Sharjah
- Emirates BioFertilizer Factory (EBFF, 2010)
- Zenath Recycling and Waste Management LLC composting facility

Many other companies have emerged in the UAE to provide organic waste management technology solutions through digester machines for establishments, hospitality and households. One

Table 4. Technical specifications of compost produced through Tadweer composting plant (Tadweer Waste Treatments LLC, 2021).

Parameter	Analysis
Nature (origin)	Organic
Colour	Dark brown
Treatment	Bio-decomposition heats up to 75°C for minimum 15 days
Smell	Natural black forest soil
Physical soil support (water retention capacity)	Natural fibres from green and wood waste
Moisture content	<25%
Electrical conductivity	Less than 8 mS cm^{-1} (typical for the country)
Sodium chloride (NaCl)	1–1.5%
pH	6–7
Organic matter	50–60%
C/N ratio	20:1
Total nitrogen (N)	2–3%
Phosphorus content (P)	1–1.5%
Potassium (K)	1.5–2%
Nematodes, weed seeds, worm eggs, and so on	Nil

example is the Biothermic Digester by Emvees, which reduces up to 80% of the volume by digestion of the biogenous waste, using extremophilic bacteria that thrive only in high temperatures (temperatures above 75°C). The digester accepts municipal sewage sludge, sludge from Sewage Treatment Plant and Effluent Treatment Plant (output of belt press), food waste from hotels and/or restaurants, vegetable wastes from markets and packing industries, fruits and vegetable waste from supermarkets and/or hypermarkets, abattoir waste, and any other organic solid waste from industries, commercial establishments and communities (Emveestech, 2020). Another example is SmartCara, for households that converts food waste into reusable fertiliser through a combination of heating, dehydration and grinding.

In terms of demand and supply of compost in the UAE, a study was conducted in 2014 to study the amount of compost produced from agricultural waste from Dubai and Abu Dhabi (Schmidt et al., 2014). The results indicated that in the best-case scenario, the agricultural waste in Abu Dhabi would cover 6.5% of the Emirate's demand. While in Dubai, the best-case scenario would be 8.8% of the Emirate's demand. Table 5 shows for Abu Dhabi and Dubai Emirates, the total agricultural area, actual agricultural area used, compost availability, specific agricultural waste production, compost demand and the covered compost demand by offer.

Furthermore, waste-to-energy converting technology is one of UAE's newest solutions for the treatment of waste. Masdar, in partnership with Bee'ah – an environmental management company, is developing a technologically advanced waste-to-energy plant in the Emirate of Sharjah. The waste-to-energy process produces heat from waste which is then used to drive an electrical turbine. The net electrical power produced will be up to 30 MW which will be supplied directly to the Sharjah electricity grid. Moreover, the resulting flue gas coming from the waste processing will be environmentally treated before being released into the atmosphere. The project is set to be completed in Q4 2021 (Masdar, 2021).

In addition, Dubai Holding has partnered with ITOCHU Corporation, Hitachi Zosen Inova, BESIX Group and Tech Group to develop one of the world's largest energy-from-waste (EfW) facility. In line with the UN Sustainable Development Goals (SDGs), the facility will contribute to reaching the goals set by Dubai Municipality in minimising the volume of municipal waste in landfills and developing alternative energy sources and contribute to sustainable and ecologically friendly waste management in the Emirate, thereby meeting the targets outlined in the Dubai Clean Energy Strategy 2050 (ITOCHU, 2021). In Abu Dhabi, the Emirates Water and Electricity Company (EWEC) and Abu Dhabi Waste Management Center (Tadweer) announced the commencement of a competitive tender process for the development of a greenfield Waste-to-Energy (WtE) Independent Power Project (IPP). This crucial next step aims to significantly reduce waste in landfills, stimulate the economy and decrease CO_2 emissions (WAM, 2021).

In 2020, scientists from the International Center for Biosaline Agriculture (ICBA) in Dubai began a new research project called 'Sustainable Green Waste Recovery'. Under this project, scientists aim to identify and propose the most effective ways to produce compost from green waste obtained from harsh and saline environments. Green waste from such environments is typically high in lignocellulose and sodium, which affect the potential quality of the produced compost. To this end, the scientists of this project control the feedstock's physiochemical characteristics and the composting process to assess its effect on the produced compost. Transforming green waste into valuable products, such as compost that can be beneficially used for agriculture, horticulture, erosion control and many other purposes, especially in marginal environments, is of utmost importance. This can help farmers and the community to reduce the disposal cost and the cost of input supplies required for production at the farm level.

Yemen

Yemen produces approximately 3.8 million tons of solid waste every year or about 0.6 and 0.4 kg per capita per day for urban and

Table 5. The estimated compost availability and demand (kt per year) for agricultural and external road landscaping in Dubai and Abu Dhabi (adapted from Schmidt et al., 2014).

Emirates	Agricultural area (km^2)	Actual agricultural land used (km^2)	Compost availability (kt $year^{-1}$)	Specific agricultural waste produced (t km^{-2})	Compost demand (kt $year^{-1}$)	Covered total demand by offer (%)
Abu Dhabi	7528	3636	898	247	Min. 14,000 Max. 34,000	Min. 3 Max. 7
Dubai	650	391	130	333	Min. 1000 Max. 4000	Min. 4 Max. 9
Total	8178	4027	1028	580	Min. 15,000 Max. 38,000	Min. 3 Max. 7

rural dwellers, respectively (estimates for the year 2012; GIZ, 2014b). About 65% of this waste consists of biogenous material (Negm and Shareef, 2020). As government has set no policies for solid waste management, solid waste material is being disposed of in dumps with no sanitation control. Moreover, no private sector institutions are involved in solid waste management (Zabara and Ahmad, 2020). In Aden and Mukalla, wood waste is recovered on dumpsite level, but, in Sana'a, wood is used for cooking and other fuelling purposes (Forni et al., 2015). Biogenous waste, which is in abundance in Yemen, is an energy source for the production of biofuels. The use of biomass provides two benefits: environmentally friendly disposal of waste and clean production of electric power. However, there is no prominent work on composting done in Yemen (Johari et al., 2012).

Conclusion

The dramatic increase of municipal solid waste, in general, and of food and organic waste, in particular, as a result of rapid urbanisation, improvement of living standards along with changes in consumption patterns is one of the major challenges faced globally in achieving sustainability. Currently, the MENA region is facing the consequences of improper waste treatment where the ultimate way to handling has been through landfilling. The good news is that in many of the region's countries, action plans are being put forward to provide efficient services in collection and disposal of all the generated waste. However, a gap still exists in awareness and in strategies when it comes to waste prevention, segregation at source, reduction or recycling. MENA countries' municipal solid waste has a high proportion of biogenous waste that can be composted. It appears that the most economically viable, environmentally friendly and sustainable waste management approach is to adopt composting to process the biogenous waste, while waste-to-energy facilities can handle the remaining waste. These waste management strategies will not only minimise the negative environmental and social impacts of waste landfilling but will also reap economic benefits as a result of material/energy recovery.

Waste separation at source, recovery and repurposing are topics that are increasingly occupying the forefront of MENA's sustainability and climate action agenda, especially with ambitious plans, such as UAE's recent pledge to reduce its carbon emissions to net zero by the year 2050. Introducing laws and policies, such as the Polluter Pays Principle (where those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment), and tax subsidies for recycling and other eco-friendly behaviour is a recommended plan of action. However, it is also crucial that the public sector involves, supports and works closely with private entities and individuals, including environmental consultants and scientists and green small- and medium-sized enterprises (SMEs) and start-ups who are introducing innovative, data-driven and tech-enabled solutions to these pressing global problems. These solutions would aim to encourage individual-level participation and involvement by directly linking and presenting how their behaviour is correlated with a positive impact. They would also clearly track and openly share what happens to the waste when it is picked up, disposed, repurposed and recycled. Transparency, advocating and rewarding positive behavioural change and providing the necessary knowledge, tools and systems will empower individuals that they are part of the solution, starting from their homes or place of work.

It is evident from this review that the MENA countries fall into one of the two groups with regard to their capacity to swiftly adopt 'state-of-the-art', research-backed solutions to waste management – the oil-rich and wealthy GCC countries and the non-GCC countries. While the former has the financial means to recruit international companies to jump-start the solutions to their growing waste problem, they lack the research to adapt and optimise these methods to their harsh environments. The importation of the knowledge and technology which is not designed for the region must be adapted to meet the local climate and conditions. Great strides are being taken by these countries to fill this gap and billions of dollars are being invested in R&D; however, their novice inevitably paves a long way for them to reach the level of the West in matters as simple as, for example, establishing outcome-based and locally specific maximum thresholds for undesirable compounds found in compost. While the road ahead is long, it appears they are on the right track. Contrastingly, the non-GCC countries for the most part have more favourable weather conditions that are closer to some countries in the West and have deep-rooted institutions (in the temporal sense) and established bureaucracies, yet they lack the financial, institutional and political backbones to establish and sustainably run waste management facilities, whether through national or foreign resources. They also lack the regulations relating to composting which engenders problems of process monitoring and low quality of produced compost potentially posing risks to human, animal and plant health and water pollution. Composting activity should be organised through a professional association and should employ a skilled labour force using modern computing technology (Adeleke et al., 2021; Angelis et al., 2021; Valenzuela et al., 2021; Velis et al., 2021). While development agencies implement numerous projects in many of these countries, especially war-struck ones, the issues of their sustainability long after the project termination are a topic of discussion. It is paramount that these development projects invest in capacity development and governance training as much as in the technical aspect of establishing a waste management facility. Training must also be provided on the social and human dimensions, including leadership, finance management, accounting and ethics and must aid in the establishment of a robust whistle-blowing system to report acts of corruption, which is common in many of these countries.

Regardless of the path taken, one thing is for sure: waste recycling, repurposing and reusing can generate significant income. In the case of compost, billions of euros worth of fertiliser can be generated, and it does not stop there. Its trickle-down effect on the agricultural, environmental and potentially industrial sectors (carbon credits) is noteworthy.

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